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Aspects of Electron Scattering

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IN this paper we shall discuss the work which has been done recently in certain selected fields of electron scattering. Electron scattering in its widest sense is a very large subject and could not be adequately discussed in the compass of a single paper. Indeed the experimental and mathematical technics of different parts of electron scattering are so entirely different that a physicist who is thoroughly familiar with one field may be quite a stranger in another field.

When an electron passes through matter, it is in general deviated from its original direction. The change in direction may also, in some cases, be accompanied by a loss in speed. This is what we call *electron scattering*, and studies of electron scattering tell us about the forces that occur in the interactions between the electrons and the molecules of the matter through which the electrons are moving. The range over which these investigations extend is enormous. We can study the scattering of slow electrons by matter. By a *slow electron* is meant one with energy less than about 500 ev. The information so obtained tells us how the molecule as a whole acts on the electron. At the other extreme, we have the scattering of electrons with energies running into millions and billions of electron volts (ev). The scattering of these electrons can be used to gain information about the interaction of atomic nuclei and electrons. For such studies the electrons cannot be generated directly at the will of the experimenter; he has to take them as he finds them in cosmic rays. The experimental and mathematical technics and the terminology of such investigations are so entirely different from those encountered in the scattering of slow electrons that, in practice, the two fields are totally unrelated and are studied by different groups of investigators.

We shall be concerned here with certain aspects of the scattering of slow and medium energy electrons by gases. One may arbitrarily classify electrons as of medium energy if their energies lie between 500 and 50,000 ev.

What can be varied and what can be observed when electrons are scattered by matter? So far as the electrons are concerned, the only variable that appears is their speed, which can be altered at will and readily adjusted to any desired value. The matter through which the electrons pass and are scattered can be solid, liquid or gaseous. We shall limit ourselves to matter in the gaseous state. The nature of the gas can be varied, and so one can compare the ways in which electrons are scattered by different kinds of molecules. Now what can be observed? One can arrange to direct a parallel beam of electrons into a gas and measure the relative numbers of electrons scattered through different angles. The *angle of scattering* is the angle between the direction of an electron before it encounters a molecule and the direction it has after the encounter. In

general, the angle of scattering may be anything between 0° and 180°. We find that the electrons which have been scattered without loss of energy have a characteristic distribution in angle. Those that have lost a small amount of energy have another distribution in angle and those that have lost a large amount have still another distribution. It is convenient to state here, by way of a definition, that electrons which have the same energy after an encounter with a molecule as they had before are said to have been scattered *elastically*. Any encounter in which the scattered electrons have less energy than they had before the encounter is a case of *inelastic* scattering.

Perhaps the most satisfactory way to present the results of experimental investigations on the scattering of electrons by gas molecules is to pick two extreme cases; namely, the scattering of electrons by helium atoms and the scattering of electrons by mercury atoms.

When electrons are scattered elastically by helium atoms it is found that the number scattered at different angles falls off very steeply as the angle increases (Fig. 1). This is particularly true for the electrons of high energy, say, 700 ev. As one reduces the energy towards 100 ev, the curves become less steep, and, below about 75 ev, there is even a slight but definite uptrend at the larger angles.[1]

When electrons are scattered elastically by mercury atoms (Fig. 2) it is found that, for angles less than about 45°, there is much the same steep falling off as is observed for helium atoms. But for larger angles the scattering curves present a very different appearance. Now we find a series of well-marked maximums and minimums whose positions shift regularly as the energy of the impinging electrons is changed.[2] One cannot escape the conviction that there is something strongly suggestive of interferences between waves. Had these results been obtained in the early 1920's, the suggestion that here was a sort of interference phenomenon would probably not have been entertained, for then electrons were particles, and particles could not be waves. However, the results actually were obtained a few years after the appearance of wave mechanics, and so an explanation in terms of the wave aspect of electrons was immediately sought and soon found.

Since electrons and nuclei are charged particles, a natural approach to a theoretical interpretation would be to suppose that the electron approaching the atom is attracted by the positively charged nucleus with an electrostatic force varying inversely as the square of the distance, and is repelled by the atomic electrons each acting individually on it with a force also varying inversely as the square of the distance. In principle one could calculate the deviation of the path of an incoming electron for each of a variety of points of impact of the electron on the atom and thus could predict the chances of a deviation through any given angle. But in practice one can calculate the angle of scattering accurately for only one case; namely, for the deviation of the incoming electron by a single charge concentrated at a point. Even the simplest atom, that of hydrogen, has two centers of force, the nucleus and the atomic electron, both of which contribute to the deviation. This makes the problem a particular case of the famous three-body problem to which a complete solution has not been found. Obviously the problem of the scattering of an electron by more complicated atoms would be still more difficult. Thus the exact solution of the problem of the

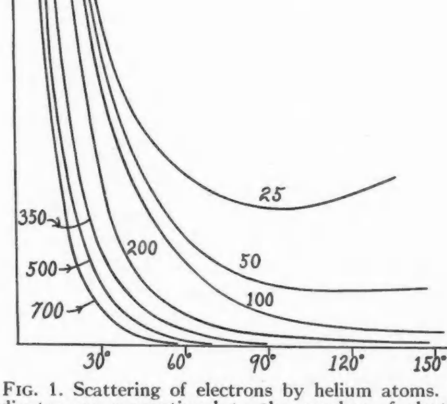

FIG. 1. Scattering of electrons by helium atoms. The ordinates are proportional to the number of electrons deviated through the angle indicated in the abscissas. The numbers on the curves refer to the energy of the incident electrons in electron volts.

[1] A. L. Hughes, J. H. McMillen and G. M. Webb, Phys. Rev. **41**, 154 (1932).

[2] F. L. Arnot, Proc. Roy. Soc. **130A**, 655 (1931).

scattering of an electron by an atom on the basis of electrostatic forces cannot be effected because of difficulties that are purely mathematical in character.

There are many instances in physics where a theory cannot be tested quantitatively because of one's inability to carry through the necessary mathematical analysis. For example, the calculation of the electric field in space that is empty except for isolated charged conductors is essentially a problem in solving the Laplace equation under boundary conditions specified by the positions and potentials of these conductors. A solution can be obtained in a few cases for which the boundary conditions are of a particularly simple type. In general, however, no exact solution can be obtained, and so no theoretical calculation which can be checked by experimental measurement is available. Yet one would not use this situation to argue against the validity of the Laplace equation for such problems. In precisely the same way, it was thought up to the early 1920's that the difficulty of explaining the scattering of electrons by atoms was just another instance of this sort. The difficulty of effecting a calculation which could be compared with experiment was attributed wholly to the limitations of available mathematical technics. It occurred to no one to question the validity of the fundamental assumption that the scattering was due to a complex set of inverse square law attractions and repulsions between the incoming electrons and the different centers within the atom. Yet it is just this assumption which wave mechanics asserts is not valid as a fundamental basis for describing electron scattering. According to wave mechanics the picture of the individual parts of the atom acting separately and independently on the incoming electron—much as the planets and the sun act on a comet entering the solar system—is unsatisfactory and must be discarded. Wave mechanics offers a totally different method of predicting the way in which electrons are scattered. According to the principles of wave mechanics, one replaces a beam of electrons by a plane wave whose amplitude squared at any point is proportional to the number of electrons to be found per unit volume at that point. The atoms are replaced by regions that are

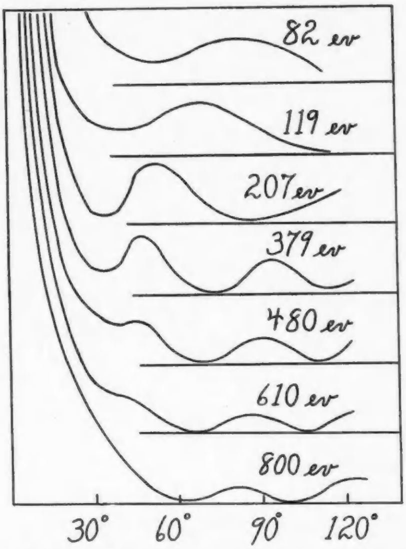

FIG. 2. Scattering of electrons by mercury atoms. The energy of the incident electrons (in ev) is shown on each curve. The ordinates are proportional to the number of electrons deviated through the angles shown on the abscissas.

roughly spherical and of suitable refractive index. The next step is to calculate the amplitude of the wave scattered in any direction by means of certain standard procedures which are well known in physical optics. In fact, the problem is very much like the scattering of a beam of light by a mist composed of droplets. Having now found the amplitude of the wave scattered in each direction, the next step is to square it and apply the rule that the square of the amplitude gives the number of electrons to be found per unit volume.[3] This is the theoretical prediction which is to be compared with experiment.

There is only one type of force field in which the methods of wave mechanics and particle mechanics give identical results, and that is when the force on a particle is due to one other particle repelling or attracting it in accordance with the inverse square law of the distance. It is necessary to add that the particles must not be identical in nature. In all other cases wave mechanics and particle mechanics lead to

[3] To be strictly accurate I should say that the wave function representing the electron beam is really a complex quantity and that, instead of squaring the amplitude to get the number of particles per unit volume, one multiplies the wave function by its conjugate.

different results. The force on an electron passing through, or passing by, an atom does not vary as the inverse square of the distance for the simple reason that no atom acts as a single scattering center. Even the simplest atom, that of hydrogen, has a field which, being due to two separate scattering centers, definitely does not vary inversely as the square of the distance from the center of the atom.

Between about 1930 and 1935 numerous experimental investigations of the scattering of electrons by each of a variety of atoms were carried out, and thus data were provided which could be used to check the wave-mechanical description of what takes place. At first the agreement in many cases was unsatisfactory. Part of this was due to the fact that the calculations are often laborious and that approximations of various degrees of validity had to be made at various steps in the application of the theory. Also it came to be recognized that certain factors, such as polarization of the atom by the incoming electron and exchange between the incoming electron and an atomic electron, often played a considerable part and had to be taken into account. It is far from correct to say that all the published experimental data have been found to be in accord with theoretical calculations based on the wave-mechanical description of the phenomenon. But in the few cases where the theoretical computations are known to be reliable, and in which everything necessary has been taken into account with reasonable accuracy, the agreement between theory and experiment is quite satisfactory. When there is disagreement, it usually is to be noted that the approximations made in the application of the theory are rather rough or that the particular calculations were made before all the effects which can influence the final result were known. On making due allowance for these apparent exceptions, it may be said with some confidence that the wave-mechanical description of the scattering of slow and medium speed electrons is adequately supported by the experimental evidence. Thus we may include electron scattering among the phenomena that support the wave-mechanical description of the atomic world.[4]

We now turn to a consideration of some experimental investigations in which the results can be accounted for quantitatively in terms of particle mechanics and for which it is unnecessary to invoke wave mechanics. It is not, of course, that the wave mechanics fails to apply. In the atomic domain the wave mechanics has been found to apply in every case in which the calculations can be carried through satisfactorily, whereas the particle mechanics gives a correct result only in a limited number of cases. It is significant that the particle mechanics is found to apply only in those limiting cases in which it is possible to regard the interaction as occurring between the electron to be scattered and one, and only one, scattering center in the atom which repels or attracts it with a force varying inversely as the square of the distance. In these cases it is more convenient to use the technic and viewpoint of particle mechanics, merely because they are simpler to handle and easier to picture.

The first question to which I propose to apply these considerations is that of the scattering of electrons by electrons. In 1913, Darwin, who was then working in Rutherford's laboratory where the pioneer work on the scattering of α- and β-particles was in progress, tackled the theoretical problem of the scattering of particles by other particles which repelled or attracted them according to the inverse square law.[5] At that time, of course, there was no wave mechanics, and there was no question as to the validity of treating the problem as one in particle mechanics. The procedures used in astronomical theory were assumed to be valid for atomic theory.

According to particle mechanics the deviation of an electron by either a nucleus or another electron is determined by two factors, the energy of the incident electron and the collision parameter. The *collision parameter* is the distance between the scattering center, be it a nucleus or an electron, and the path of the incoming electron when produced to pass the scattering center; it might be thought of as a measure of

[4] Good surveys of the scattering of electrons from both the theoretical and experimental standpoints are given by N. F. Mott and H. S. W. Massey in *The theory of atomic collisions* (Oxford Univ. Press) and by J. H. McMillen, Rev. Mod. Phys. **11**, 84 (1939).

[5] C. G. Darwin, Phil. Mag. **27**, 499 (1914).

the accuracy with which the incoming electron was aimed at the scattering center. The deflection depends on the collision parameter, being greater the smaller the collision parameter. With these ideas as a starting point it is possible to calculate the probability α of scattering an electron through an angle θ, as a function of θ. For the scattering of an electron by a nucleus, the probability is

$$\alpha=(Z^2e^4/4m^2v^4)\operatorname{cosec}^4(\tfrac{1}{2}\theta), \tag{1}$$

where Z is the number of unit charges on the nucleus, v is the velocity of the incoming electron, and e and m are the charge and mass of the electron. For the scattering of one electron by another electron, the probability α_1 of an electron traversing a path making an angle θ with that of the incoming electron is

$$\alpha_1=(e^4/m^2v^4)4\cos\theta(\operatorname{cosec}^4\theta+\sec^4\theta). \tag{2}$$

When the method of wave mechanics was applied to the problem, it was found that the result for the scattering of an electron by a nucleus attracting it with an inverse square force was identical with that calculated by means of particle mechanics, and so Eq. (1) is also that given by wave mechanics. However, in the particular case where the scattered and scattering particles are indistinguishable from each other—for example, when electrons are scattered by other electrons—wave mechanics predicts a formula which differs significantly from that predicted by particle mechanics. The wave mechanics formula is

$$\alpha_2=(e^4/m^2v^4)4\cos\theta(\operatorname{cosec}^4\theta+\sec^4\theta-\operatorname{cosec}^2\theta\sec^2\theta). \tag{3}$$

Equation (1) differs from Eq. (2) for two reasons: first, because the nucleus is so massive that it is unaffected by the collision whereas the atomic electron is generally knocked out of the atom; and second, because, after an encounter between two electrons, there is no way to determine whether it was the incoming electron or an atomic electron that was knocked out of the atom. Equations (2) and (3) differ because the wave-mechanical description of a collision between two like particles involves a peculiar interference phenomenon between the waves representing the particles. Such a phenomenon cannot be imagined when one considers a collision from the point of view of particle mechanics. Here then is a clear-cut issue that can be put to the test of experiment. An examination of Eqs. (2) and (3) will show that the divergence between them is greatest at 45°, when the probability of scattering calculated by wave mechanics is just half what it is when calculated by particle mechanics.

A method for deciding between the two formulas was worked out by Dr. S. S. West and myself.[6] The result was decisively in favor of the wave mechanics formula, thus illustrating once again that when wave mechanics and particle mechanics disagree, experiment invariably confirms the wave mechanics description. In our investigation a parallel beam of electrons was directed into helium gas at a low pressure. The function of the helium gas was to provide a sufficient number of target electrons in a small volume, for each helium atom consists of one nucleus and two electrons. If the electrons in the beam are sufficiently fast, they will, in general, pass through this mixture of nuclei and electrons without appreciable deflection. Only a few will by chance pass close enough to a scattering center to be strongly deviated from their original paths, and practically none will be acted upon successively by two centers. This is what is meant by *single scattering*, a condition necessary for the direct application of the theory to the experimental data. The electrons which are deviated by passing close to a nucleus lose no energy; that is, the collision is *elastic*. On the other hand, those which are deviated by an electron in the atom undergo *inelastic* collisions; that is, they are left with a smaller amount of energy, $V=V_0\cos^2\theta$, where V_0 is the energy of the electron before collision, V is its energy after collision and θ is the angle of scattering. Thus it is possible clearly to distinguish between the electrons that have been scattered by nuclei and those that have been scattered by electrons, and to measure the proportion of each for different angles of scattering. It is convenient to express the experimental results and theoretical predictions in terms of the ratio of the

[6] A. L. Hughes and S. S. West, Phys. Rev. **50**, 320 (1936).

number of electrons scattered by the atomic electrons to the number scattered by the nuclei as a function of the angle of scattering. The upper and lower curves in Fig. 3 represent the predictions of particle and wave mechanics, respectively. The dots, which are accompanied by vertical lines showing the probable error, indicate what was found by experiment. Clearly the experimental results support the wave mechanics description rather decisively.

We now turn to a consideration of how suitable experiments on electron scattering can be made to give information as to the velocities with which the electrons are moving around inside an atom or molecule. To describe the state of an electron in an atom or molecule, we must know two things: the location of the electron and its momentum. These are considered to be known for our purpose when we can state (1) the probability of finding an electron in any volume element and (2) the probability of its momentum having any given value. Although these two factors are of equal importance in describing the state of the electrons in an atom, practically no attention has been paid to the momentum distribution, while an immense amount of theoretical and experimental work has been done on the location of electrons in an atom. The location of an electron in an atom is directly involved in the numerous investigations on the atom form factor[7] and the self-consistent field.[7] Recently it has become possible to make a start in the study of the momentum distribution among the atomic electrons by means of properly selected experiments on electron scattering. Since electrons in the light atoms, especially those in the outer shell, are moving with speeds for which the relativity mass correction is unimportant, one may use the term *atomic electron velocity* interchangeably with *atomic electron momentum*, for one is proportional to the other.

It has already been stated that when one

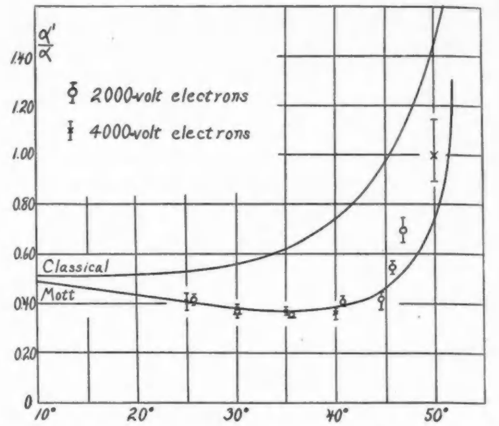

FIG. 3. Scattering of electrons by atomic electrons. The ordinates are the ratios of the number of electrons scattered by atomic electrons to the number of electrons scattered by nuclei. The upper continuous curve is that given by particle mechanics; the lower curve is that given by wave mechanics. The short vertical lines denote the estimated probable errors.

shoots a beam of electrons of sufficiently high velocity into a gas, such as helium, at low pressure, the electrons which are scattered through a considerable angle, say 35°, have been deviated from their original path by a single scattering center, which may be a nucleus or an atomic electron. Thus it is convenient to think of the gas as merely providing a mixture of nuclei and electrons, only one of which produces an appreciable effect on a fast electron which may be driven through the mixture. Nothing was said previously as to the velocity of an electron in this mixture; we now suppose each electron to have the velocity which it has as part of a particular atom. The criterion for the degree of independent action is the ratio of the collision parameter for the observed path deviation to the average distance apart of the scattering centers in an atom (Fig. 4).

When sufficiently fast electrons are scattered through a considerable angle by atoms, such as helium, there should be two well-separated groups of electrons: those that have lost no energy and therefore were scattered by nuclei, and those that have lost energy and therefore were scattered by atomic electrons. We find that the electrons which were scattered by the nuclei all have one and the same energy, but

[7] The *atom form factor*, sometimes known as the *atomic structure factor*, is "a quantity occurring in the expression for the intensity of an x-ray beam reflected by a crystal, whose value depends on the varying configuration of the electrons in the crystal atoms relative to the center of the atom, as well as upon the angle of incidence and the wave-length of the x-rays." The *self-consistent field* is "the central field used by Hartree in the calculation of atomic wave functions." See L. D. Weld, *Glossary of physics*.

those which were scattered by atomic electrons have a distribution of energies. If the atomic electrons had been at rest before the collision, then the principles of conservation of energy and of momentum require that the electrons moving away in a direction θ must all have the same energy, $V_0 \cos^2 \theta$. The reason why the electrons scattered by the atomic electrons do not have the same energy is that the atomic electrons are not at rest before the collision, but may be moving in any direction and with any velocity. The energy with which an electron emerges from such a collision in any given direction will be determined by the direction and the magnitude of the velocity of the atomic electron just before collision.

In principle, therefore, it should be possible to secure information as to the velocities of atomic electrons from an experimental study of the distribution of energies among the electrons which are scattered at a suitably chosen angle. It can be shown that the shape of the curve for the distribution of energies among the electrons scattered at any fixed angle is an exact copy of the shape of the curve for the component velocities of the electrons in the atom, except for a scale factor which can easily be evaluated. Knowing the component velocity distribution for the atomic electrons, it is easy to calculate the distribution of total, or resultant, velocities among the electrons. However, this is seldom done; it is customary to consider the problem solved when the component velocity distribution is found.

The apparatus for determining the distribution of atomic electron velocities consists of three parts (Fig. 5). There is an *electron gun* whose purpose is to fire a beam of electrons into the

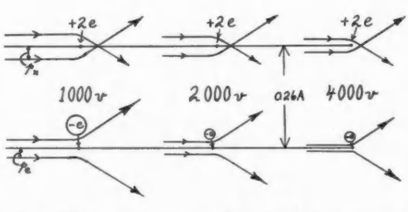

FIG. 4. Collision parameters (p_e and p_n) for the scattering of electrons of various energies from 1000 to 4000 ev by a helium nucleus and by an atomic electron in relation to the average distance apart between the nucleus and an atomic electron in the helium atom.

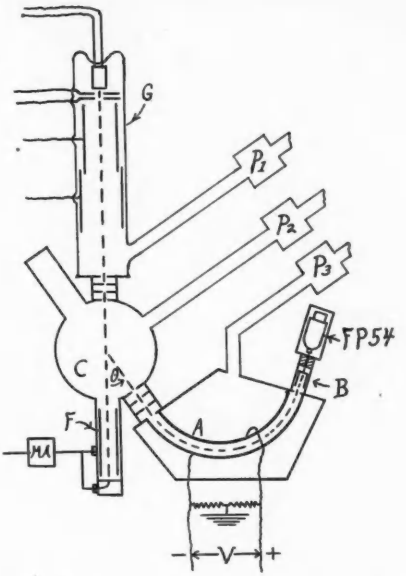

FIG. 5. Apparatus for investigating the distribution of energies among the electrons scattered through 34° by helium atoms.

gas under investigation in the collision chamber. The gas pressure is kept low so that the probability of any electron suffering two collisions is negligibly small. Next, there is a *direction selector* which accepts only those electrons that have been scattered through 34°. Finally, the electrons pass through an *electrostatic analyser* by means of which the distribution of energies among the scattered electrons can be measured. Since the curve for the distribution of energies among the scattered electrons has exactly the same shape as that for the distribution of component velocities among the atomic electrons, all that one has to do is to take the curve obtained experimentally for the scattered electron energy distribution and, by means of a factor determined by the experimental parameters, re-label the abscissas so that the curve now gives the distribution of component velocities among the electrons in the atom. This completes the experimental part of the problem. It is unnecessary to convert the component velocity distribution curve into a resultant, or total, velocity distribution curve for two reasons: (1) the theoretical physicist can express the

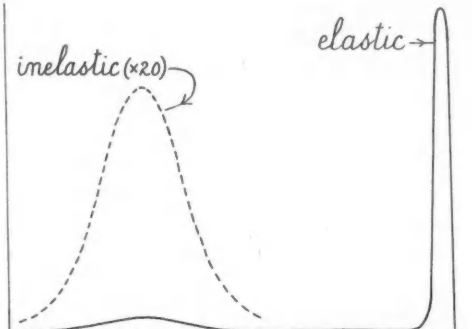

FIG. 6. The distribution of energy among the electrons scattered through 34° by helium atoms. *Ordinates* are proportional to the scattered electron current. *Abscissas* denote the energy of the scattered electrons. The elastically scattered electrons all have the same energy; those scattered inelastically have a broad distribution of energy.

results of his computations in terms of component velocities just as easily as in terms of resultant velocities; (2) according to theory, the component velocity distribution curve has a shape that is identical with the profile of the modified band in the Compton effect when x-rays are scattered by the same gas.

The first experiments were made on helium.[8] Figure 6 shows the distribution of energies among the electrons scattered through 34° by helium atoms, when the energy of the electrons in the beam is 4000 ev. The separation of the scattered electrons into two groups is clearly evident. First we have the electrons that have been scattered elastically by the nuclei; all these have, as was to be expected, the same energy. Then we have the electrons that have been scattered by the atomic electrons. These have a broad distribution in energy about the energy value which they would have had if the atomic electrons had all been at rest. The shape of this band gives the shape of the curve for the distribution of component velocities; to get absolute values, all that one needs to do is to change the abscissas from energy to component velocity by means of the scale factor previously mentioned.[8] The distribution of component velocities among the atomic electrons in helium atoms is shown in Fig. 7. The two continuous lines represent the values computed by Hicks from a wave-mechanical starting point. According to him the curve *H-4* is based on a more accurate method of approximation than the curve *H-2*. The curve *K.R.R.* is due to Kirkpatrick, Ritland and Ross. The dots are the experimental points obtained from our measurements on electron scattering. The agreement with the curve *H-4* is extremely satisfactory. When these experiments on electron scattering were almost completed, DuMond and Kirkpatrick published an account of their investigations on the profile of the modified band in the Compton effect observed where x-rays are scattered by helium.[9] From the profile of this band, the curve for the distribution of component velocities among the atomic electrons was calculated. It turned out to be identical with the curve which Dr. M. M. Mann and I obtained from the electron scattering measurements. It may therefore be said that two entirely different experimental methods and a theoretical computation are in complete agreement as to the distribution of velocities among the atomic electrons in helium.

The technic was next applied to determine the distribution of velocities among the atomic electrons in hydrogen. There is this time a definite discrepancy between the experimental curve and that computed theoretically by Hicks for the hydrogen molecule. It amounts to a difference of 11 percent in the width at half-maximum. An investigation on the profile of the modified band in the Compton effect for x-rays scattered by hydrogen was completed by DuMond and Kirkpatrick shortly after our results were published. Their curve again agreed excellently with ours, the difference in the width at half-maximum being only about 1 percent. This agreement between the results obtained by electron scattering and those obtained from Compton effect investigations, for both helium and hydrogen, is very satisfactory. It seems extremely unlikely that the same kind of experimental error could be involved in two such utterly different experimental procedures as those of ours on electron scattering and of DuMond and Kirkpatrick on the Compton effect.

[8] A. L. Hughes and M. M. Mann, Phys. Rev. **53**, 50 (1938).

[9] J. W. M. DuMond and H. A. Kirkpatrick, Phys. Rev. **52**, 419 (1937).

We may therefore place considerable reliance on the results given by each of these methods. The discrepancy which exists between the experimental results and theoretical calculation for hydrogen but which did not exist for helium is to be attributed to the formidable technical difficulties met with in applying wave mechanics to a molecule, even when it is the simplest of all molecules.

Experiments were then carried out on nitrogen and methane to determine the distribution of velocities among the electrons in the molecules of these gases. Since the energy of the incident electrons was not high enough to give information about the velocities of the K electrons in these molecules, the results obtained refer to all the electrons in the molecule other than the K electrons. Unfortunately, no studies of the Compton effect in these gases have been attempted and, as there were then no theoretical calculations available, a comparison of our results with others could not be effected.

The most recent application of electron scattering has been suggested as a method for securing information about the state of electrons in chemical bonds. The general idea is this. In hydrocarbons we recognize single C−to−C bonds as in ethane, double C−to−C bonds as in ethylene and triple C−to−C bonds as in acetylene. We may expect that the distribution of velocities among the electrons in a bond will be characteristic of that type of bond and will

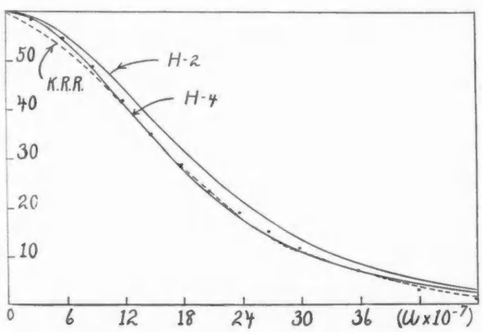

FIG. 7. Theoretical and experimental distributions of component velocities of atomic electrons in helium. The ordinates are proportional to the number of atomic electrons having component velocities between u and $u+du$. The abscissas are the values of the component velocity u. Continuous lines, theoretical curves due to Hicks; dots, experimental values.

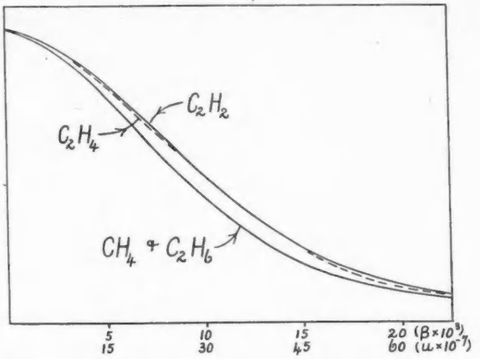

FIG. 8. The distribution of component velocities among the electrons in the molecules of acetylene, ethylene, ethane and methane. The ordinates are proportional to the number of electrons having a component velocity between u and $u+du$. The abscissas are the values of the component velocities (or the equivalent β's).

appear as a contribution to the actual distribution of velocities for a molecule in which that particular bond appears. So far as hydrocarbons go, we may expect, as a first approximation at any rate, to have only four distinct distributions —those corresponding to the C−H bond and to the single, double and triple C−to−C bonds. It is possible that the overall distribution of velocities for the bonding electrons in any hydrocarbon is made up of these four fundamental distributions, each suitably weighted. As a specific example, let us consider benzene. On one view there are three double C−to−C bonds containing altogether 12 electrons, three single C−to−C bonds containing altogether 6 electrons, and six C−to−H bonds containing altogether 12 electrons. If, by some independent means, one could establish the shapes of the distribution curves for each of the bonds, he could predict what the overall distribution for the molecule should be and then compare it with the distribution obtained by experiment. This provided an incentive for preliminary experiments on methane, ethane, ethylene and acetylene. If, for the moment, we assume that the electrons in the C−H bonds in all these molecules have the same distribution and that the velocities of the electrons in the C−to−C bonds get higher in passing from single to double to triple bonds, we may expect a regular change in the velocity distribution curves as we replace

one gas by another in the order named. Actually it turns out from experiments[10] that the distributions for methane and ethane are substantially identical as are also those for ethylene and acetylene (Fig. 8). One may perhaps account for the substantial identity of the distribution curves for methane and ethane on the ground that there are but two electrons in the single C—to—C bond in the ethane molecule, whereas there are 12 electrons in the C—to—H bonds in the same molecule. Thus the C—to—H bonds would be weighted six times as heavily as the C—to—C bond in the overall distribution. Therefore, if the distribution curve for the C—to—C bond does not differ greatly from that for the C—to—H bond, it is easily seen why the methane and ethane distribution curves are practically identical. However, no such explanation can be offered for the substantial identity of the distribution curves for ethylene and acetylene.

When this investigation was begun it was assumed that the state of the electrons in the C—H bond did not depend on the adjacent bonds and so one could associate just one velocity distribution curve with the electrons in the C—H bond; and this presumably would carry through all compounds containing this bond. During the last few months, several theoretical papers by Coulson and Duncanson[11] in England have appeared on the distribution of velocities among the bonding electrons in hydrocarbons. According to these authors, the state of the electrons in a C—to—H bond is not always the same but is determined to some extent by the nature of the adjacent bond. The average velocity of the electrons in the C—to—H bond is least when it is adjacent to a triple C—to—C bond, as in acetylene, and is greatest when it is adjacent to a single C—to—C bond, as in ethane. One may assume, on general considerations, that the closer together the carbon atoms are in a bond, the faster the bonding electrons in them move. The calculations of Coulson and Duncanson verify this. Thus, as we go from ethane through ethylene to acetylene there is an increase in the velocities of the electrons in the C—to—C bond, but, as we have just mentioned, this is accompanied by a slight decrease in the velocities of the electrons in the associated C—to—H bonds. The result is that the spread to be expected between distribution curves for the molecules of ethane, ethylene and acetylene will not be as great as it would have been, had there been just one distribution for the C—to—H bond wherever it appears. Our experimental curves are decidedly wider than the theoretical curves of Coulson and Duncanson, which means that the average velocity of the electrons in the bonds of the molecules studied is considerably larger than that calculated theoretically. Such a discrepancy might conceivably be due to some peculiarity in the apparatus resulting in distortion of all the results in the same way, or it might be due to the use of some unsatisfactory assumption in the theoretical calculation of the absolute electron velocities. However, one would expect the relative positions of the curves to be much less affected by considerations of this sort than are their absolute values. We shall therefore consider the relative positions of the curves as determined by experiment and as calculated by theory. The theoretical investigation by Coulson and Duncanson indicates that the distribution curves at half-maximum for ethane and acetylene should differ in width by 14 percent while the curve for ethylene should lie approximately halfway between. Our experimental results for ethane and acetylene differ in width at half-maximum by 12 percent, but our ethylene curve is much closer to the acetylene curve than it is to the ethane curve.

Now let us recall what led to these experiments on electron scattering by hydrocarbons. It was thought that the electrons in any one of the different types of bonds appearing in hydrocarbons would have a distribution of velocities characteristic of that bond. Then if one knew what these were, he could calculate the distribution of velocities to be observed for the whole molecule by properly weighting the contributions of the various bonds it may happen to contain. Should the calculation agree with experiment, the inference would be that the assumed structure was correct and that each bond carries with it, as a sort of identifying label, its own

[10] A. L. Hughes and T. Enns, Phys. Rev. **60**, 345 (1941).
[11] C. A. Coulson and W. F. Duncanson, Proc. Camb. Phil. Soc. **37**, 55, 67, 74, 397, 406 (1941).

characteristic electron velocity distribution. This idea is complementary to the one in which, by means of electron diffraction experiments, it is established that the characteristic single, double and triple C–to–C spacings carry through all molecules involving these bonds.

It is unlikely that any hydrocarbon will give a distribution curve lying outside the extreme curves found by us and which differ in width at half-maximum by only 12 percent. Consequently, to make a really effective check on the calculated velocity distribution for any hydrocarbon would require high precision in the experimental measurements. Unfortunately the currents associated with the scattered electrons as measured in our experiments are very small and, in fact, never exceed 5×10^{-15} amp. It is extremely difficult and very tedious to measure such small currents to an accuracy of less than 1 percent. However, should it turn out that information of the kind obtained by electron scattering is of sufficient importance to physical chemists, and that such information can be obtained only by the method of electron scattering, no doubt technics can be developed to give the necessary precision in the experimental measurements.

The Teaching of Ferromagnetism

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INSTRUCTION in ferromagnetism has never been an easy part of the college course in physics. There seems to be a fundamental difficulty in teaching this subject to beginners, a difficulty associated with the concepts of intensity of magnetization, magnetic induction, hysteresis and the many other concepts commonly used in describing the phenomena. The difficulty is not lessened by the duplication of terms—for example, *magnetic induction* and *flux density*—and the different meanings given to any one term—for instance, *permeability*. Hysteresis is sometimes omitted in a beginning "descriptive" course because it is not easily comprehended, and incremental, reversible and differential permeabilities are almost never mentioned.

Although the history of this branch of physics is relatively old, there was a period of 20 or 30 years during which progress in the theory and practice of ferromagnetism was very slow; and it may be significant and unfortunate that some of the authors of present-day college textbooks were doing their most intense study in that period. This might account partially for the fact that many textbooks still present the facts and theories as they were known in 1900.

At the suggestion of the editor of this journal, the author has read the sections on ferromagnetism in some 20 commonly used textbooks on general physics and on intermediate and advanced electricity and magnetism, and in this article will try to point out the discrepancies between the facts and theories presented and those considered to be important by the people working intensively in the field. Little consideration has been given to the method of presentation used in these textbooks; rather, attention has been given to the material with the understanding that those who have had experience in teaching will know the best ways to get these facts and theories into the minds of the students.

Needless to say, there are considerable differences in the quality judged on the basis of subject matter alone. Of one book intended as a first text in college physics, it is hardly an exaggeration to say that there is no mention of advances made since the time of Weber. In another book, no important changes are needed, and most of the minor defects are a result of advances made since the book was published five years ago.

ANALYSIS OF MATERIAL

The textbook material studied may be classified as follows: (1) description of various ferromagnetic materials; (2) the magnetization curve and the domain theory; (3) the atomic structure of ferromagnetic elements.

(1) Ferromagnetic Materials

The magnetic properties of magnetite and iron are usually described first because of their historical significance. The magnetization, or B *versus* H, curve for iron is drawn, and, for comparison, the curves of cobalt and nickel are given. Often curves for steel and cast iron are shown and occasionally one for a Heusler alloy.[1] Almost invariably there is no mention of silicon-iron alloys, probably the most commonly used magnetic materials, and of the iron-nickel alloys[2]—permalloys—the materials that have the highest permeabilities and are most commonly used where high quality is more important than cost. The high saturation of the iron-cobalt alloys is of considerable scientific and some practical interest, and sometimes is noted, as is also the iron-cobalt-nickel alloy, perminvar.

Mention of materials for permanent magnets is usually omitted completely. Carbon steel is occasionally referred to, and a few authors mention cobalt steel, first reported in 1920.[3] Permanent magnets of this material are said (1935) to be "the strongest," whereas in fact the much stronger iron-nickel-aluminum alloys —"Alnicos"—were reported in 1932[4] and the still stronger "Ticonals," later, in 1940.[5] The maximum energy products (factors of merit) of these materials are, respectively, 0.2, 1.0, 1.7 and 4.5 gauss oersted$\times 10^6$. Chromium, tungsten and molybdenum steels are also commonly used in industry but are seldom mentioned. A summary of commonly used materials is given in Table I.

TABLE I. Properties of some permanent magnet materials.

Material	Composition (percent)	H_c (oersted)	B_R (gauss)	$(BH)_m$ (gauss $\times$oersted)
Carbon steel	0.8 C, 0.9 Mn, 98 Fe	45	9,500	0.2×10^6
Cobalt steel	36 Co, 7 W, 3.5 Cr, 0.5 Mn, 0.7 C, 52 Fe	220	9,500	0.9×10^6
Alnico 2	12 Co, 17 Ni, 10 Al, 6 Cu, 55 Fe	530	7,600	1.6×10^6
Ticonal 3.8 or Alnico 5	24 Co, 14 Ni, 8 Al, 3 Cu, 51 Fe	550	12,500	4.5×10^6

In some textbooks the excellent plan is followed of tabulating the values of H, I, B, κ and μ for some common material. Unfortunately, the values given are for materials as they were made at the turn of the century. For example, one author's table is for iron having a maximum permeability μ_m of 2600; a more representative specimen now has $\mu_m = 5000$ to 10,000. In the table, it would be instructive to fill in μ and κ for $H=0$, and I for $H=\infty$ or for some large value of H. Data for representative specimens of annealed iron and of the iron-silicon alloy containing 4 percent silicon are given in Tables II and III.

TABLE II. Magnetic properties of annealed iron.

H (oersted)	I (cgsm)	$\kappa[=I/H]$ (cgsm)	B (gauss)	$\mu[=B/H]$ (cgsm)
0.0	0	20	0	250
.1	2.5	25	32	320
.2	6	30	76	380
.4	16	40	200	500
.6	31	52	390	650
.8	115	145	1,440	1800
.9	250	280	3,150	3500
1.0	360	360	4,500	4500
1.3	570	440	7,200	5500
1.5	660	440	8,300	5500
2	830	415	10,400	5200
5	1110	220	14,000	2800
10	1250	125	15,500	1550
100	1350	13.5	17,000	170
1,000	1700	1.70	22,400	22
10,000	1710	0.17	31,500	3

If space allows, it is advantageous to include a figure, similar to Fig. 1, showing the intensity of magnetization I in a strong field as a function of the temperature.[6] This shows the continually more rapid decrease in I as the Curie point is approached and gives more meaning to this

[1] E. Take, Verh. d. deut. phys. gesell. **12**, 1059–1084 (1910); curves are reproduced in *International Critical Tables* (1929), vol. 6, p. 409. See also L. A. Carapella and R. Hultgren, Phys. Rev. **59**, 905 (1941).

[2] G. W. Elmen, "Magnetic alloys of iron, nickel and cobalt in communication circuits," Elec. Eng. **54**, 1292–1299 (1935).

[3] K. Honda and S. Sato, Phys. Rev. **16**, 495–500 (1920).

[4] T. Mishima, "Magnetic properties of iron-nickel-aluminum alloys," Iron Age, p. 346 (Sept., 1932). J. Q. Adams, "Alnico—its properties and possibilities," Gen. Elec. Rev. **41**, 518–522 (1938).

[5] As described by J. F. Kayser, "Permanent magnets," Engineering **170**, 183 (Sept. 20, 1940).

[6] F. Hegg, Arch. Sci. Phys. Nat. [4] **30**, 15–45 (1910).

temperature. Further phenomena[7–9] that might be mentioned are magnetostriction, the effect of stress on magnetization, and the effects of magnetization on electric resistivity, on specific heat and on Young's modulus.

(2) The Nature of Changes in Magnetization

The best accounts of the theory of the magnetization curve describe its three main parts, shown in Fig. 2, and interpret each in terms of the domain theory. In the initial portion of the curve, the changes in magnetization are nearly reversible—when the field is applied and then removed, the magnetization increases and then decreases again almost to zero. In this range, the μ, H curve (but not the B, H curve) is linear. In the middle portion of the curve occur most of the energy losses associated with hysteresis; and in this region the Barkhausen effect[10] is pronounced, and microscopic powder patterns,[11] some of which are reproduced in Fig. 3, show distinct local changes in magnetization. The remanent magnetization increases rapidly with the strength of the applied field. In the upper portion of the curve, above the knee, the change is again largely reversible as the magnetization approaches saturation.

In interpreting these changes in terms of the domain theory,[7–9] it is difficult to describe the theory both simply and accurately. If the magnetic material has been severely cold-worked, and, as a result, the directions of the domains are controlled by large internal strains, the changes occurring in the initial portion of the curve are due to the rotations of the domains. By this, it is meant that the magnetic moment of each atom of a domain changes its direction continuously with increasing field strength, the moments of all of the atoms in the domain remaining parallel. On the other hand, if the material is well annealed, rotations do not occur and the changes in magnetization that take place in weak fields are the result of the almost

TABLE III. Magnetic properties of commercial hot-rolled silicon iron sheet, annealed.

H (oersted)	I (cgsm)	$\kappa[=I/H]$ (cgsm)	B (gauss)	$\mu[=B/H]$ (cgsm)
0.0	0	32	0	400
.05	7	143	90	1800
.1	21	215	270	2700
.2	66	330	830	4150
.3	160	500	2,000	6300
.4	240	600	3,000	7500
.6	390	650	4,900	8200
.8	510	640	6,400	8000
1.0	590	590	7,400	7400
1.5	720	480	9,000	6000
2	800	400	10,000	5000
4	950	240	11,900	3000
6	1000	167	12,600	2100
10	1060	106	13,300	1330
100	1310	13.1	16,500	165
1,000	1530	1.5	20,200	20
10,000	1530	0.2	29,200	2.9

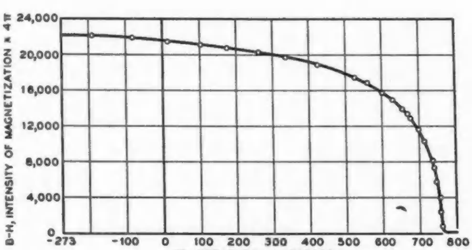

FIG. 1. Dependence of the magnetization of iron on the temperature, according to Hegg.[6] $H = 10{,}000$.

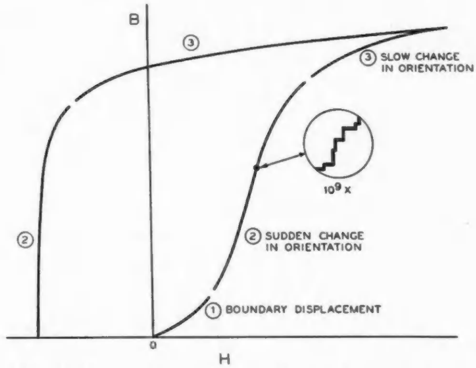

FIG. 2. Illustrating the three kinds of change in magnetization and their relation to the magnetization curve and hysteresis loop. The transition between the different processes is not as sharp as indicated.

[7] R. Becker and W. Döring, *Ferromagnetismus* (Springer, Berlin, 1939).
[8] E. C. Stoner, *Magnetism and matter* (Methuen, London, 1934).
[9] R. M. Bozorth, "The physical basis of ferromagnetism," Bell Syst. Tech. J. **19**, 1–39 (1940); "The present status of ferromagnetic theory," Bell Syst. Tech. J. **15**, 63–91 (1936).
[10] R. M. Bozorth and J. F. Dillinger, Phys. Rev. **35**, 733–752 (1930).
[11] F. Bitter, *Introduction to ferromagnetism* (McGraw-Hill, 1937), pp. 55–66 by W. C. Elmore. L. W. McKeehan and W. C. Elmore, Phys. Rev. **46**, 226–228 (1934).

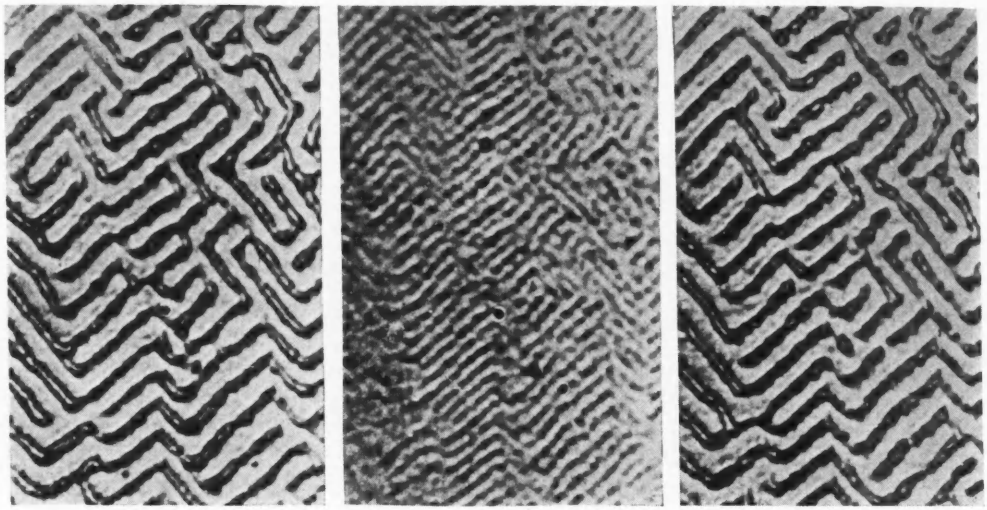

FIG. 3. Powder patterns for iron[11]: *left*, field outward; *middle*, demagnetized; *right*, field inward.

continuous movement of domain boundaries. The directions of the magnetizations of the domains in this case are parallel to the crystal axes if the material is like iron—positive magnetic anisotropy—or are equally inclined to all three cubic axes if it is like nickel—negative anisotropy.

The middle portion of the magnetization curve is invariably accompanied by sudden changes in magnetization and is more simply described. Whole domains change in magnetization suddenly and presumably by 180° in annealed or unannealed material, and by 90° in ironlike crystals or by the tetrahedral angle of 109° (or 71°) in nickel-like crystals. For changes of this kind, it is difficult and unimportant to say whether or not the change is by boundary displacement; in either case, the direction of magnetization of the whole domain is changed suddenly.

In the final stage of the magnetization process, the continuous rotation of domains takes place without boundary displacement, in both annealed and unannealed material. Various stages in the magnetization of an annealed ironlike material are illustrated in Fig. 4.

(3) Atomic Structure of Ferromagnetic Materials

One of the most fundamental problems of magnetism is to explain in terms of atomic structure and interatomic forces the difference between ferromagnetic and nonferromagnetic

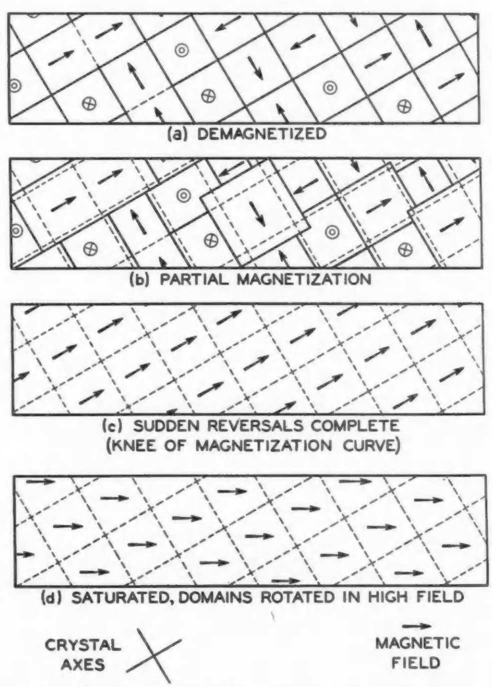

FIG. 4. Diagram illustrating changes in domain structure in a single crystal. Domains are shown as cubes, for convenience; they are believed to be long and narrow.

materials. A necessary prerequisite for the description of the present-day theory of this difference is an understanding of the elements of the *Bohr theory* and the nature of the *spinning electron.* The necessary conditions for the existence of ferromagnetism at low temperatures are:

(*i*) Unfilled inner shell of electrons (net angular momentum$\neq 0$);
(*ii*) Atoms not too close together.

The shell must be unfilled so that it may have a finite moment, and must be an inner shell in the free atom so that it will remain as an unfilled shell when the atom becomes part of the metal and the outer electrons become free. In the iron group, the unfilled shell (3*d*) is near the outside and has only one or two valence electrons beyond, while in the rare-earth elements (at least one of which, gadolinium, is ferromagnetic[12]) this shell (4*f*) is more deeply buried and has one complete shell between it and the valence electrons. Figure 5 is a diagram of the shells in an atom of iron. Figure 6 illustrates condition (*ii*).

The exchange interaction between neighboring atoms causes their moments to be either parallel or antiparallel, depending on the distance

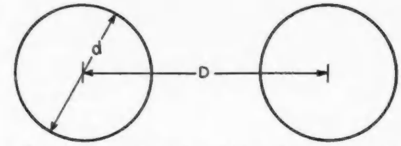

FIG. 6. Incomplete shells in neighboring atoms. In ferromagnetic substances,[14] D/d exceeds 1.5.

between the atoms as compared with the diameter of the shell responsible for the moment. Parallelism of magnetization of adjacent atoms, and so ferromagnetism, occurs only when the atoms are far enough apart.[13] The ferromagnetism of the Heusler alloys, as well as of commoner alloys and pure metals, is consistent with this view, as has been pointed out by Slater.[14] A description of exchange interaction is, of course, too difficult for undergraduate textbooks.

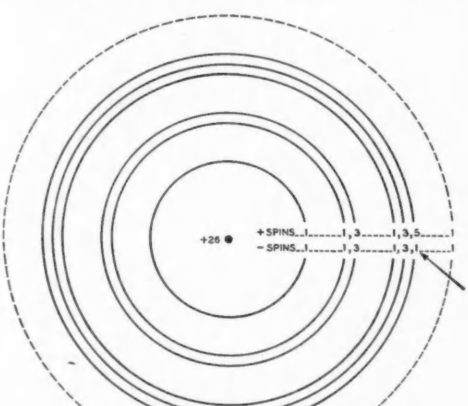

FIG. 5. Electron shells in an isolated iron atom. The arrow indicates the incomplete subshell that is responsible for ferromagnetism in the metal. The numbers specify how many electrons with each spin (+ or −) are in the corresponding subshells.

COURSES IN ELECTRICITY AND MAGNETISM

In making the preceding brief analysis, the writer has had in mind the general course in physics. The same remarks may be made concerning the more advanced courses dealing with electricity and magnetism, except that one expects the latter to include a more thoroughgoing description of all phases of ferromagnetism. More emphasis is to be given to the discussion of measuring instruments and methods, and to a detailed description of materials and their use in commercial apparatus.

Examination of a number of books used as texts in such a course shows that they are farther behind the times than books on general physics. In many of them there is no mention of atomic structure and in almost all of them the descriptions of material, behavior and theory are far from up to date. Perhaps the best way to emphasize this assertion is to cite some of the shortcomings observed.

In one book, published in 1937, the only ferromagnetic materials discussed in any detail are iron and steel. Mumetal, electron metal and permanent magnet materials containing chromium, tungsten or manganese up to 4 percent (coercive force up to 50 oersteds) are mentioned

[12] G. Urbain, P. Weiss and F. Trombe, Comptes rendus **200**, 2132 (1935).

[13] H. Bethe, article on "Magnetism," *Handbuch der Physik* (1933), vol. 24, pt. 2, pp. 595–598.

[14] J. C. Slater, "Atomic shielding constants," Phys. Rev. **36**, 57–64 (1930).

in a brief paragraph. This account thus gives the student scant information about materials and no information at all concerning iron-silicon alloys, some of the important permalloys and alloys of iron-cobalt and iron-cobalt-nickel, and above all, the many superior materials used in permanent magnets. There is no discussion of the magnetic properties of single crystals. The data on magnetostriction used by the author were first published in 1888; yet more representative data are now available. A typical error is made in ascribing to nickel a coercive force of 7.5 oersteds; this value is representative of the material available in 1900, whereas at the present time the appropriate value is 0.7 oersted. In the whole chapter on materials there are 30 references to original sources, and the average of the years of the references is 1898. Two pages are devoted to the Ewing hysteresis tester, long since obsolete.

On the theoretical side there is a rather detailed account of Ewing's theory of the magnetization curve and the Weiss theory of the molecular field, and the value of the Bohr magneton is derived after an exposition of the Bohr theory. No attempt is made to elucidate the nature of the molecular field or to relate the atomic moment to a specific shell of the Bohr atom. Weiss domains, according to the book, still behave as they did in 1907 when they were invented.

All of this is from one of the better textbooks on electricity and magnetism. The list could be continued almost indefinitely by quoting from other textbooks. One author of a book on electromagnetic theory devotes a single page to a description of the general properties of ferromagnetic materials and dismisses them with the remark that they are of great practical importance, but further consideration is out of place there. It is a question whether this is a proper point of view when so much of the use of electromagnetic theory is in reference to materials that have a permeability varying with field strength.

Material commonly found in books on electricity and magnetism includes, quite properly, discussions of the following subjects: Rayleigh's law for weak fields, Steinmetz's law for hysteresis in intermediate fields, Fröhlich's law for strong fields, the properties of single crystals, the effects of heat treatment, the magnetic circuit (magnetomotive force, reluctivity and flux), demagnetizing factors, the "energy product" of materials for permanent magnets, and various problems connected with the use of materials in transformers, motors, shields and other apparatus.

SUMMARY

The more important items discussed in the foregoing pages are listed briefly in the following outline. This outline is intended to call attention to the various topics which may be considered for inclusion in a textbook or used in the classroom to supplement a textbook in general physics.

(1) Materials and properties

(*a*) High permeability materials: iron; cobalt; nickel; alloys of iron-silicon, iron-nickel, iron-cobalt, iron-cobalt-nickel; Heusler alloys; single crystals.

(*b*) Dependence of μ, H_c, and so forth, on purity and heat treatment; independence of I_s.

(*c*) Permanent magnet materials: carbon-steel, chromium and tungsten steels, cobalt steel, iron-cobalt-nickel-aluminum alloys; heat treatment of some of these materials in a magnetic field.

(*d*) Values of H, B, I, μ and κ for ordinary iron or iron-silicon (Tables II and III).

(*e*) Effect of temperature and stress on magnetization; effect of magnetization on length, resistivity, specific heat, elastic moduli, and so forth.

(2) Magnetization curve and domain theory

(*a*) Three parts of curve:

(*i*) *Initial:* $\mu_0 \neq 0$, μ versus H curve linear (Rayleigh's law).

(*ii*) *Middle:* hysteresis (Steinmetz's law); Barkhausen effect and powder patterns.

(*iii*) *Upper:* slow approach to saturation (Fröhlich's law).

(*b*) Domain interpretation:

(*i*) Random directions when $B=0$ (spontaneous magnetization).

(*ii*) Boundary shifts or rotations (small values of B).

(*iii*) Sudden reorientations (intermediate values of B).

(*iv*) Slow rotations (near saturation).

(*v*) Domain size.

(3) Atomic structure

(*a*) Bohr atom.

(*b*) Spinning electrons.

(*c*) Unfilled inner shells.

(*d*) Atoms not too close together.

(4) Applications

Compass, transformer, motor and generator, relay (tractive force), shielding.

Polymathean Professors

William Smith—John Ewing—David Rittenhouse

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UNDER the date of May 24, 1754, a young Scotchman bearing the somewhat Anglo-Saxon name of William Smith wrote in his diary, "I was this day inducted Provost of the College and Academy of Philadelphia and Professor of Natural Philosophy."

If this entry had been correct, the University of Pennsylvania might claim to have set up the first professorship in America solely devoted to physics, just as it claims to have set up the first independent chair of chemistry. But the entry did not tell the whole truth. As the minutes of the corporation reveal, Provost Smith was appointed "professor of Logick, Rhetorick, Ethicks, and Natural Philosophy."

Today the combination seems inclusive, to say the least. Logic and natural philosophy are closely enough related, but rhetoric and ethics hardly go with physics, at least as far as the present organization of education is concerned, and surely no professor would now be expected to spread his accomplishments so wide, except perhaps in some missionary institution where he might even be called upon to engage in some of the defensive tactics of the art of war.

It would be easy to excuse the difference between what a man was expected to do in 1754 and what we are used to today solely on the basis of the number of students, financial resources and the availability of qualified in-

William Smith, D.D., first Provost of the University of Pennsylvania—the College of Philadelphia, as it was known during his incumbency—an astronomer, mathematician, engineer, man of letters and educational theorist. Besides organizing the first genuinely liberal curriculum in America, at the College of Philadelphia, he founded Washington College in Chestertown, Maryland. The portrait was painted by Gilbert Stuart in 1800.

structors. Fewer than 200 students were enrolled in both the college and academy that the Reverend William Smith headed; only seven received their degrees at the first commencement in May, 1757; tuition was only four pounds; professors received £150 a year and upward—Provost Smith, £200—and the minutes of the corporation and the voluminous extant correspondence show that the trustees had to scratch pretty deep and wide to find their men. In the case of William Smith they even had to agree to his return to England to be ordained, which, it seemed, was an essential, even in a college promoted principally by Benjamin Franklin.

For a clergyman, the teaching of logic, ethics and rhetoric would not be evidence of unusual versatility. But there can be no doubt that William Smith might very well have taught Latin and Greek in addition and certainly metaphysics, for any Scotch divine, trained at the University of Aberdeen, who could not venture into the upper reaches of speculative thought would hardly be worth his salt. The Provost could even have taught mathematics and astronomy, if his later activities are any indication.

For one thing, his officially designated repertory did not seem ill-assorted to William Smith. To the young professor—he was only twenty-six when appointed—*knowledge*, *science* and *philosophy* were virtually synonymous terms. Here are his pronouncements to the first graduating class:

> A person who knows himself endued with reason and understanding, will not be content to take his knowledge entirely at second hand, on subjects so important as the nature and fitness of things, and the *Summum Bonum* of man; he will not care to rely wholly on a Historical Knowledge, founded on the Experience and Testimony of others; however much his labors may be shortened thereby. He will think it his duty to examine for himself, and to acquire a Moral and Physical knowledge; founded on his own Experience and Observation. This is what we call Philosophy in general; comprehending in it the knowledge of all things Human and Divine, so far as they can be made the objects of our present inquiries. Now the genuine branches of this Philosophy or great system of Practical Wisdom, together with the necessary instrumental parts thereof, may be included under the following general heads; it appearing to me that the nature of things admits of no more:

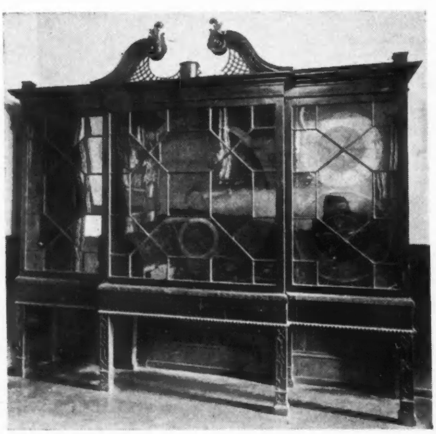
College buildings on the first campus of the University of Pennsylvania at Fourth and Arch Streets, Philadelphia, at about the year 1762. "Philosophical apparatus" was kept on the second floor of the building on the left, where there was a large auditorium. Following oratorical fireworks at commencements and similar high occasions, guests were entertained by electrical displays and other demonstrations of physical experiments.

> 1. Languages, which have been already mentioned rather as an Instrument or Means of Science, than a Branch thereof.
> 2. Logic and Metaphysics, or the Science of the Human Mind; unfolding its powers and directing its operations and reasonings.
> 3. Natural Philosophy, Mathematics, and the rest of her beautiful train of subservient arts, investigating the Physical properties of Body; explaining the various phenomena of Nature; and teaching us to render her subservient to the ease and ornament of Life.
> 4. Moral Philosophy, applying all the above to the business and bosoms of men; deducing the laws of our conduct from our situation in life and connexions with the Beings around us; settling the whole Œconomy of the Will and Affections; establishing the predominancy of Reason and Conscience, and guiding us to Happiness thro' the practice of Virtue.
> 5. Rhetoric, or the art of masterly Composition; just Elocution, and sound criticism; teaching us how to elevate our wisdom in the most amiable and inviting garb; how to give life and spirit to our Ideas, and make our knowledge of the greatest benefit to ourselves and others; and lastly, how to enjoy those pure intellectual pleasures, resulting from a just taste for polite letters, and a true relish for the sprightly Wit, the rich Fancy, the noble Pathos, and the marvelous Sublime, shining forth in the works of the most celebrated Poets, Philosophers, Historians and Orators, with beauties ever pleasing, ever new.

"Thus," he concluded, "I have given a sketch of the Capital branches of Human Science; and all of them are professed and taught in this Institution." And if the boys who heard him were supposed to have absorbed all this in the three years of their college course (for, of course, there were no electives), what would be strange in the

assumption that a single professor might teach it? His only limitation would be the time available for instruction, not his inability to absorb the necessary knowledge.

And the tradition of polymathean professors, whose academic chairs were so wide as to resemble settees, was a long time dying—perhaps it should never have died completely—and we find, according to James Truslow Adams' *Epic of America*, that as late as 1870 "one unfortunate professor [at Columbia] had to teach mental and moral philosophy, English literature, such history as was called for, political economy and logic." At the University of Pennsylvania at about the same time another professor, who certainly did not regard himself as unfortunate (nor did his students so regard themselves), had an even wider repertory. This was Dr. Robert Ellis Thompson, a Presbyterian, not an Anglican divine like William Smith, who began his professorial career as a teacher of mathematics, then shifted to history and English literature, and at last became professor of "social science," largely because his work in history and English had received strong infusions of economics, political science, and even international law.



The only extant specimen of an "orrery" made by David Rittenhouse. Now restored, the instrument stands in the "Franklin Room," in the Library of the University of Pennsylvania. Rittenhouse, an unusual craftsman as well as scientist, made both the case and the complex mechanism. William Smith, first Provost of the University and an associate of Rittenhouse in a number of scientific enterprises, went on a personal lecture tour to raise funds for making the orrery. [Courtesy of the Philadelphia Museum of Art.]

Such situations, of course, owed something to practical considerations like numbers of students and other educational resources, and also to the highly personal kind of instruction as is exemplified by Mark Hopkins, whose academic seat might have been one end of a log and who was at Williams from 1830 to 1872, four years before the opening of Johns Hopkins and the real introduction of graduate work and academic specialization in America.

But this was only a part of a tradition at least as old as Aristotle's *Rhetoric*, which clearly recognized that the art of composition must concern itself with subject matter as well as form, that subject matter frequently determines the form, and that beautifully expressed ignorance is not sound composition—an excellent doctrine, but one which sometimes turns classes in composition and public speaking into mere discussions of current events and ideas and has led to the ironical remark that no one knows more about economics and government than a teacher of public speaking.

Furthermore, if Aristotle could undertake all human knowledge, from natural history and physics to poetics and rhetoric, might not a modern university professor? That was the belief at least at William Smith's own university, Aberdeen, where, from the time of its establishment until 1798, there prevailed a pedagogic practice known as "regenting." Under this system professors did not teach particular subjects but were in charge of all the instruction given a class from the time of its entrance until graduation.

But even so, natural philosophy does not seem quite in place in the program that Provost Smith undertook. Rhetoric is persuasive; physics is a science, objective and unemotional. And any scientist who resorts to emotional appeals should be looked on with suspicion. Was it because William Smith happened to know something of natural philosophy and no one else was available? The latter is hardly the case: the first teacher of English at the Academy of Philadelphia was the irascible David Dove, an English schoolmaster, who, so Franklin tells us, had come to America "with an apparatus for giving lectures in experimental philosophy"; and Dove's successor, the first professor of English in the College, was

TABLE I.
VIEW OF THE PHILOSOPHY SCHOOLS.

FORENOON.

	INSTRUMENTAL PHILOSOPHY	
FIRST YEAR.	LECTURE I.	LECTURE II.
Freshmen. May 15. First term. Three months.	Lat. & Engl. exercises cont.	Common arithm. reviewed. Decimal arithmetic. Algebra.
Second term. Three months.	The same.	Fractions and extract. roots. Equations, simple & quadrat. Euclid, first six books.
January. Third term. Four months. Remarks.	Logic with Metaphysics. N.B. At leisure hours disputation begun.	Euclid a second time. Logarithmical arithmetic.
SECOND YEAR. Juniors. May 15. First term. Three months.	Logic, &c. reviewed. Surveying and dialling. Navigation.	Plain and spherical Trigonom.
Second term. Three months.	Conic sections. Fluxions.	Euclid, 11th book. ———12th ditto. Architecture, with Fortificat.
	MORAL PHILOS. begun.	NAT. PHILOS. begun.
January. Third term. Four months. Remarks.	Viz. Compend of Ethics. N.B. Disputation continued.	Viz. gener. propert. of body. ———Mechanic powers. ———Hydrostatics. ———Pneumatics. N.B. Declamation and public speaking continued.
THIRD YEAR. Seniors. May 15. First term. Three months.	Ethics continued. Natural and civil Law.	Light and Colours. ——Optics, &c. Perspective.
Second term. Three months.	Introduction to civil History. ——to Laws and Government. ——to Trade and Commerce.	Astronomy. Nat. Hist. of Vegetables. ——— of Animals.
January. Third term. Four months.	Review of the whole. Exam. for Degree of B. A.	Chemistry. Of Fossils. Of Agriculture. N.B. Thro' all the years, the French language may be studied at leisure hours.

Ebenezer Kinnersley, Franklin's fellow-experimenter and an independent discoverer of the two kinds of electricity, which he called "resinous" and "vitreous."

Actually, William Smith had a considerable amount of mathematical and astronomical knowledge, and to that he might very readily add sufficient acquaintance with the comparatively simple apparatus devised up to that time by physicists—Leyden jars, electrostatic generators, and vacuum pumps. Franklin, whose formal education was virtually nil, gives little evidence of possessing more than the barest knowledge of physical theory and mathematics. Yet he was an acute observer and a daring experimenter, and his principal discovery is a classic in physical research. Certainly Smith was qualified to teach the subject.

But what is especially interesting is that for him it was a fundamental in the educational

TABLE I.—*Continued.*

	AFTERNOON.	PRIVATE HOURS.
FIRST YEAR.	Classical & rhetoric. studies	Books recommended for improving the youth in the various branches.
	LECTURE III.	
Freshmen. May 15. First term. Three months.	Homer's Iliad. Juvenal.	Spectator, Rambler, &c. for the improvement of style, and knowledge of life. Barrow's Lecture's. Pardie's Geometry. Maclaurin's Algebra. Ward's Mathematics. Keil's Trigonometry. Watts' Logic, and Supplement. Locke on Human Understanding. Hutcheson's Metaphysics. Varenius's Geography. Watts' Ontology and Essays. King de Orig. Mali, with Law's Notes. Johnson's Elem. Philosophy.
Second term. Three months.	Pindar. Cicero, select parts. Livy resumed.	
January. Third term. Four months.	Thucydides, or Euripides. Well's Dionysius.	
Remarks.	N.B. Some afternoons to be spared for declamation this year.	
SECOND YEAR. Juniors. May 15. First term. Three months.	Introduction to rhetoric. Longinus, critically.	Vossius. Bossu. Pere Bohours. Dryden's Essays and Prefaces. Spence on Pope's Odyssey. Trapp's Prælect. Poet. Dionysius Halicarn. Demetrius Phalereus. Stradæ Prolusiones. Patoun's Navigation. Gregory's Geometry.—on Fortification. Simson's Conic Sections. Maclaurin's and Emerson's Fluxions. Palladio by Ware. Helsham's Lectures. Gravesande. Cote's Hydrostatics. Desaguliers. Muschenbroek. Keil's Introduction. Martin's Philosophy. Sir Isaac Newton's Philosophy. Maclaurin's View of ditto. Rohault per Clarke.
Second term. Three months.	Horace's Art. Poet. critically Aristot. Poet. &c. critically. Quintilian, select parts.	
	COMPOSITION begun.	
January. Third term. Four months.	Cicero pro Milone. Demosthenes pro Ctesiphon.	
Remarks.	N.B. During the application of the rules of these famous orations, imitations of them are to be attempted on the model of perfect eloquence.	
THIRD YEAR. Seniors. May 15. First term. Three months.	Epicteti Enchiridion. Cicero de Officiis. Tusculan Quæst. Memorabilia Xenoph. Greek	Puffendorf by Barbeyrac. Cumberland de Leg. Sidney. Harrington. Seneca. Hutcheson's Works. Locke on Government. Hooker's Polity. Scaliger de Emendatione Temporum. Preceptor. Le Clerc's Compend of History.—Gregory's Astronomy. Fortescue on Laws. N. Bacon's Discourses. My lord Bacon's Works. Locke on Coin. Davenant. Gee's Compend. Ray Derham. Spectacle de la Nature. Religious Philosopher.——Holy Bible, to be read daily from the beginning, and now to supply the deficiencies of the whole.
Second term. Three months.	Patavii Rationar. Temporum Plato de Legibus. Grotius de Jure, B. & P.	
January. Third term. Four months.	Afternoons of this third term, for composition and declamation on moral and physical subjects.—Philosophy acts held.	

scheme. Here is what he had to say in describing the activities of the boys who were to be in his charge in the year 1754–55:

From October till February or March we shall be employ'd in reading some ancient Compositions critically, in applying the Rules of Rhetoric and in attempting some Imitations of these most finished Models in our own Language. This I take to be the true way of Learning Rhetoric, which I should choose to put off until after the study of natural Philosophy had we any apparatus ready, because in order to

write well we should have at least a general notion of all the sciences and their relations one to another. This not only furnishes us with sentiments but perspicuity in writing.

And a little later he indicates how fundamental was physics in his scheme of education. Commenting on the educational program devised at King's College by Dr. Samuel Johnson, he says (not too grammatically):

> There is no Matter by his scheme. No ground of Moral Obligation. Life is a Dream. All is from the immediate Impressions of the Deity—Metaphysical Distinctions which us Men and surely no Boy can understand.

The point is that the studies pursued in the College of Philadelphia combined to form a genuinely liberal curriculum, intended to serve as a groundwork. After graduation the student would add to his knowledge through active participation in his chosen calling. As Doctor Smith later wrote concerning the curriculum that he devised:

> Concerning the foregoing plan, it is to be remarked that life itself being too short to attain a perfect acquaintance with the whole circle of the sciences, nothing can be proposed by any scheme of collegiate education, but to lay such a general foundation in all the branches of literature, as may enable the youth to perfect themselves in those particular parts, to which their business, or genius, may afterwards lead them; and scarce any thing has more obstructed the advancement of sound learning, than a vain imagination, that a few years spent at college, can render youth such absolute masters of science, as to absolve them from all future study.

—a sound doctrine that is being rediscovered today, even in engineering schools!

Nor is it surprising that mathematics and physics should be so prominent in the curriculum. The first provost's own bent may well have been scientific rather than metaphysical and theological, but no doubt he was elected by the trustees for that very reason. It needs hardly to be stated here that the institution that has now become the University of Pennsylvania was founded principally through the efforts of Benjamin Franklin and of his fellow-experimenters. Of these, Thomas Hopkinson and Philip Syng, like Franklin, were trustees; and Ebenezer Kinnersley, the first professor of English. Naturally, therefore, we find the curriculum heavily weighted with scientific studies, much more so than would appear in the usual collection of courses elected by today's undergraduates. The complete course was set forth in tabular form in the *Pennsylvania Gazette*, again in an article appearing in the October, 1758, issue of the *American Magazine*, and finally in Doctor Smith's collected works.

According to this schedule, the undergraduates attended three lectures a day, two in the morning and one in the afternoon. The latter were labeled "Classical and Rhetorical Studies," the former, "Instrumental Philosophy," which seems to indicate that they were regarded as practical studies. "Instrumental Philosophy," which naturally included physics, was taught in the morning, unlike our present practice of reserving the afternoons for laboratory work. Latin and English exercises, as Table I reveals, were evidently considered of practical value, and so were logic, ethics and metaphysics. The rest we would certainly consider practical today, and it is especially interesting to find that a part of the second term of the second year was devoted to architecture and fortifications, the professor undoubtedly being the Provost himself. Even the classical studies had a practical slant, for the works in Greek and Latin included Plato's *Laws*, Cicero's *de Officiis* and Grotius' *de Jure*.

This curriculum, extending as it did from Greek and Latin classics to agriculture, architecture and even fortification, undoubtedly spread its educational content pretty thin; and no one would advocate its adoption today. Yet one can venture that plenty of our educators would prefer to see such a program elected by liberal arts students than what many now choose. And not only teachers of the sciences would say with Provost Smith that training in natural philosophy would improve the perspicuity of student composition.

It was a good curriculum and well suited to the job it was expected to do. If Greek and Latin are not so highly regarded in the twentieth century, they were then expected of the college graduate, and ignorance of them would have resulted in loss of respect. Even if the curriculum was not intended as training for the church, many graduates did become clergymen, and we may observe that Greek is still required in the seminaries. Latin, on the other hand, was of definite practical

utility—to prospective members of the professions and to scientists, for important works continued to appear in that language. Even the practical Ben Franklin, who insisted that the study of one's native language was of first importance, declared in his *Proposals relating to the education of youth in Pensilvania* (1749) that Greek and Latin were:

> two of the best Languages that ever were, the most expressive, copious, beautiful; and that the finest Writings, the most correct Compositions, the most perfect Productions of human Wit and Wisdom, are in those Languages which have endured Ages, and will endure while there are Men; that no Translation can do them justice, or give the Pleasure found in Reading the Originals; that those Languages contain all Science; that one of them is become almost universal, being the Language of Learned Men in all Countries; that to understand them is a distinguishing ornament, &c.,

all of which is as eloquent a tribute as even a professor of the classics could desire.

As for the rest of the curriculum, it was designed to prepare young men for life in a new country, where versatility and adaptability were necessary. Commerce, the professions, agriculture, government, even military life, one or many of these might call and did call the graduates of William Smith's college.

And the first provost himself, with his many activities is as good an example of this versatility as we can find. If the many-sided Benjamin Franklin is properly regarded as a typical American—perhaps the first, as James Truslow Adams suggests—William Smith is a good specimen, too. Like Franklin he was hard-headed and skeptical, as we have seen; and unlike Franklin he was an influential and eloquent clergyman. He was a frequent occupant of the pulpit of Christ Church, which adjoined the college grounds, and actually was elected Bishop of Maryland, though never consecrated. As early as 1759 and again in 1762 his sermons were printed in England, and later editions were brought out in Philadelphia at the time of his death. His very first published effort, preached in Christ Church in 1754 on the death of a favorite pupil, contained, so said a writer in the *Monthly Review*, "strokes equal to any in the *Oraisons Funèbres* of Bossuet."

Like Franklin, he was also concerned with politics, but unfortunately on the other side of the fence. One of his sermons will serve to introduce this side of his character. It was preached on May 21, 1756, a day of fast appointed by the government of Pennsylvania following Braddock's defeat. Taking as his text, Jeremiah VIII, 7–11, the Provost likened the citizens of Pennsylvania to the Jews whose corruption the mournful prophet excoriated. No persons or parties were named in the Provost's call to repentance, but during the year before he had published in England two pamphlets in which he charged that the Pennsylvania Assembly, dominated by the Quakers and their friends the Germans, had failed to protect the borders of the Province. Naturally, the point of the Jeremiad was clear enough to all, and feelings ran high.

Another political venture followed shortly. Judge Moore, of Chester, Pennsylvania, having been accused of various offenses, most of them political, the Assembly addressed a formal request to the governor for his removal from office. This was followed by an attack on the Assembly by Judge Moore which appeared in a German newspaper. The Assembly then charged that Provost Smith had had a hand in the attack and jailed both the Judge and the Provost, the former for contempt, the latter for libel. Although Doctor Smith might have gone free had he offered apology and retraction, he preferred to go to jail, where he stayed for three months, holding classes there with permission of the trustees and, presumably, the jailer. The students, of course, were boys. Another visitor to the old jail at Sixth and Walnut Streets was Rebecca, the attractive daughter of Judge Moore, whom Doctor Smith married on June 3, 1758, a few weeks after his liberation.

Like Franklin, Provost Smith was also an editor (though not a printer). In October, 1757, appeared the first issue of the *American Magazine and Monthly Chronicle*, which he edited during its brief existence of a year. Although tinged with politics, the publication also contained many contributions concerned with religion, philosophy, science and education. Poems by a favorite pupil of the Provost, Francis Hopkinson, celebrated for his satirical verse and as the first

native composer of music, also appeared in it and a few by another pupil, Thomas Godfrey, author of the first play to be written and produced in America. Of the *American Magazine*, Frank Luther Mott says: "There was more original material in it than in any other American magazine."

Like Franklin, Doctor Smith was also something of a versifier himself, carrying on that activity rather later in life than did the boy who slipped anonymous contributions under the door of his brother's print shop. If Franklin's verses cannot be said to be very successful, the Provost's cannot either. An excellent sample are the following from a poem of 270 lines, "On Visiting the Academy of Philadelphia":

Heavens! how my Heart beat Rapture, to behold
The little *Heroes*, decent, graceful, bold,
The *Rostrum* mount, with *British* Ardor warm'd,
And, by the sacred Soul of *Glory* charm'd,
With Hands out-stretched, rowl, tingling, from their Tongue,
Sage Truths of *Justice*, *Freedom*, *Right*, and *Wrong*,
In numerous Periods, sweeter than my Song.
O how the *Sires* glow'd round, and fed their Eyes
Fix'd on their darling Sons in sweet surprize;
O how the *Sons* were smit with conscious Fires,
In the animating Presence of their *Sires!*

A less reverent age might well remark that as a poet, the Provost would make a good physicist!

Like Franklin, the Provost also traveled to Europe to obtain support for a young and struggling institution, not to France for aid to the Republic, but to England for aid to the College. In 1762, on his arrival, he found an emissary from King's College there on a similar mission. Unfortunately the field did not appear fertile enough for both to cultivate it separately, and so they agreed to pool their efforts and the harvest. Although Doctor Smith did not regard the trip as a success, his two years of solicitation brought close to £7,000 to his college, or nearly £12,000 in Pennsylvania money.

But all of this reveals little of his attainments as a scientist, or more particularly as a natural philosopher. Of his success as a teacher of physics we have little evidence to go on. His greatest influence on the young seems to have been in the direction of literature, art and politics. There were, for instance, Francis Hopkinson and Thomas Godfrey. He also showed an interest in Benjamin West early in the latter's career and was clearly responsible for the young artist's visit to Europe, from which he never returned. It was West who later said: "Dr. Smith, the Provost of the College, had largely contributed to elevate the taste, the sentiment and topics of conversation in Philadelphia."

On the scientific side there was Hugh Williamson, a member of the first graduating class, who, in addition to being a member of the Constitutional Convention, gained international fame as a physician and as author of *Observations on the climate of America*. Hopkinson, too, showed plenty of interest in science. The story is told that a Hessian officer, commissioned at the time of the British occupation of Philadelphia to burn the homes of the worst rebels, went promptly to Hopkinson's house, but finding it filled with apparatus, he did not have the heart to carry out his orders, even though the owner was a signer of the Declaration of Independence.

That there was plenty of instruction in natural philosophy under Provost Smith is attested to not only by the curriculum but by the commencement programs. For instance, one of the few of these extant, that of 1762, reveals that the students, parents, and distinguished guests were obliged to listen to the defense of a grand total of 89 theses by the students, presumably in Latin, since their titles were in Latin. Of these, the *Theses Physicae* were the most numerous, 15 in all, the *Theses de Jurisprudentia Naturali*, a subject also taught by the Provost, being next with 13. The physical theses related to gravitation, magnetism and electricity, hydrostatics, optics, and astronomy, of which the following two are samples:

12. The resistance of fluids is in the ratio of the square of the velocity: the impetus of a fluid in motion has also the same ratio.

14. Two men cannot see the same rainbow at the same time.

Of the soundness of the defense of these theses, we have no means of knowing, but we can be pretty sure that they were in accord with Newtonian principles and the observation of the fairly simple electrical and other experiments devised up to that time.

But perhaps the best evidence of Provost Smith's scientific interests lies in his connection

with the American Philosophical Society, which, as is generally known, has been concerned from the beginning not with what we call philosophy today but with natural philosophy, including natural history and architecture. The Society in its present form was organized in 1769, with Franklin as its president and William Smith as the first named of its four secretaries. It was he, it is asserted, who drew up its "Laws and Regulations."

It is evident that a principal reason for the organization of the American Philosophical Society was the desire of the members to participate in the observation of the transit of Venus due to occur on June 3, 1769. The Society named a committee to undertake observations on the State House Square in Philadelphia, at Cape Henlopen and at Norriton, Pennsylvania, the home of David Rittenhouse. William Smith, Dr. John Ewing and Charles Thompson, later "Perpetual Secretary" of the Continental Congress, were prominent members of the committee.

Modern accounts of the investigation of the solar parallax indicate that the observations made in 1769 were unsatisfactory. In the neighborhood of Philadelphia, however, the weather was perfect, and the American astronomers arrived at an angle of 8.805", which is astonishingly close to the figure of 8.80", long accepted now by international agreement, and the 8.790" figure announced in December, 1941. Perhaps this remarkable accuracy was the result of mere chance, but we should give our Colonial astronomers due credit.

Doctor Smith played a prominent part in the observations. At Norriton he was in charge of a Gregorian reflector made by Nairne, and in addition he contributed three of twelve papers

David Rittenhouse, M.A., LL.D., F.R.S., first Professor of Astronomy at the University of Pennsylvania and first Director of the United States Mint, which he constructed and equipped. He is regarded by many as the greatest American scientist of the eighteenth century and in his own day as the rival of Newton and Leibniz. Observing the effect of temperature on clocks, he made a metallic thermometer, for the invention of which Breguet received credit a century later. A very practical project was his attempt to bring order into American weights and measures, which failed, and so we have 96 kinds of bushels in the United States. The portrait, painted by Charles Wilson Peale in 1772, hangs in College Hall, University of Pennsylvania.

on the phenomenon that appeared in the first volume of the *Transactions* of the Society. One of these, "The Sun's Parallax Deduced," is the longest (16 pages) and final paper of the series. Another astronomical paper in the volume is Smith's account of the transit of Mercury, on November 9, 1769, as observed by him and Rittenhouse at Norriton. All of these papers are filled with what seem to the layman intricate mathematical and astronomical calculations, some of which were carried out by Smith and Rittenhouse jointly and the rest by Smith alone —and all of which reveal that the secretary of the American Philosophical Society was not a mere clerical dabbler in astronomy.

So much has been said of the varied activities of Provost Smith that little space remains to tell about two other early teachers of natural philosophy at the College of Philadelphia (or the University of Pennsylvania) who show a similar variety of achievement. These were Dr. John Ewing, William Smith's successor as Provost and Professor of Natural Philosophy, and David Rittenhouse, who needs no identification.

Doctor Ewing's education was informal in the extreme, even though he graduated from Princeton. Born the son of a Maryland farmer of little means but many children, he received a desultory elementary education from Francis Alison, later Professor of Moral Philosophy at the University of Pennsylvania, who then conducted a school at New London, Pennsylvania. Alison was able to give little instruction in mathematics; yet, because of an avid interest in the subject, the boy John Ewing acquired a remarkable knowledge of it for himself. Through Alison's interest, he went to Princeton in 1754, where he became a favorite pupil of President Burr and, in spite of having to fill in gaps in his education outside the regular curriculum and even to do some tutoring of pupils in the Academy, he graduated in one year. He then prepared himself for the ministry by studying with Alison and was ordained a Presbyterian minister. Instead of taking a church, however, he returned to Princeton to teach mathematics. In 1758, when Provost Smith was in England, he took over the latter's classes in Philadelphia and in 1759 was appointed minister of the First Presbyterian Church, a charge that he retained until his death. In 1762, when Provost Smith again went to England, he was appointed Professor of Natural Philosophy, and in 1779, when the Pennsylvania Assembly ousted the trustees and Provost of the College of Philadelphia and set up the University of the State of Pennsylvania on the old foundation, he became provost.

Provost Ewing's scientific career is of as much interest as Provost Smith's. It seems probable that it was he who proposed to the American Philosophical Society the elaborate observations of the transit of Venus, and he was in charge of the group in the State House Square, where a wooden platform was erected for the astronomers. This platform was not removed and from it the Declaration of Independence was first read publicly.

The Provost also had something of a career as an engineer and surveyor of boundary lines, a precedent set for him by Provost Smith, who in 1763 had made surveys with Rittenhouse to determine the possibility of running a canal from Lake Erie to the Delaware River and so prevent the loss of trade to New York and Baltimore. But such surveys were naturally conducted under governmental authority, and since Doctor Ewing, like Rittenhouse, was a strong republican and therefore more in favor with the Pennsylvania and national governments, he had considerably more activity of that sort than Doctor Smith.

There was much of it to be done. Charles II, a confirmed Indian giver, had handed out and rescinded charters right and left; the original surveys were inexact; and, oddly enough all the early charters were granted with the notion that a degree of longitude or latitude contained only 60 English miles. It was not until 1671 that Picard announced in France the correct distance. Colonists being a litigious and otherwise contentious lot, many disputes hung on and much surveying of boundaries occurred just before and after the Revolution, astronomers, with their knowledge of mathematics and instruments, like Mason and Dixon, being the ones usually employed. Since John Ewing was professor of natural philosophy (which included astronomy) in the university with the greatest scientific reputation of the time, it was natural that he be selected to help run the boundary line of the

state of Delaware, to settle boundary disputes between Pennsylvania and Virginia, Massachusetts and Connecticut, and also to survey the most practicable route for a turnpike between Philadelphia and Lancaster.

Because the country was rough and filled with forests and the forests in some cases with Indians, it would seem that he must have possessed considerable physical stamina and courage. One story told of him reveals a good deal of courage, though hardly of a physical sort. In 1773, to solicit funds for an academy at Newark, Delaware, he traveled to England, where he met the overpowering Doctor Johnson. Although warned that he must not cross the great man in any way, he defended the Colonists when Johnson called them rebels and scoundrels. "Sir," demanded Doctor Johnson, "what do *you* know in America? You never read. You have no books there." Dr. Ewing's reply was a retort courteous: "Pardon me, sir, we have read the *Rambler*," which resulted in instant pacification.

But plenty of both physical and moral stamina was needed to carry through the Provost's regular routine. In addition to his duties as professor and provost, he prepared one sermon a week and sometimes two for delivery in his church, and faithfully carried out the usual pastoral duties of visiting the sick and troubled, of marrying, christening, and burying. In spite of this severe regimen, he remained in good health until 1796, when, according to his early biographer, Robert Patterson—his successor as Professor of Natural Philosophy, Director of the United States Mint and President of the American Philosophical Society—"he was attacked with a violent disorder which it required a long time to subdue." This must have been a stroke, for Patterson continues: "He never, however, recovered from its effects; but although it left him so feeble as to be unable to walk without aid, he still persevered in performing his public duties."

Something of Doctor Ewing as a teacher of physics can be learned from two books in the library of the University of Pennsylvania. One of these is a small, calf-bound student notebook, in appearance very like an eighteenth-century novel. What would be the title page of a printed book has on it in elaborate penmanship: "A Compend of Natural Philos; by Rev'd John Ewing, Provost of the University of Philadelphia [*sic*] Vol I, Philadelphia, January 13th, 1789." The flyleaf is ornamented with a carefully drawn elevation of a two-story Georgian building—not the University's lecture hall—which is surrounded by pen-and-ink medallions in classic style, one of them containing an uncomplimentary nude figure labeled G.R.R. (George III?). No student's name appears anywhere.

The first page of the notebook at once reveals something of the ecclesiastical background of the professor, for the text begins in a catechistical manner:

Q. What is Natural Philosophy?
A. It is a science that investigates y^e^ reason & causes of the various phænomina of Nature making the truth or probability evident to our senses by plain & adequate experiments.
Q. What do you mean by y^e^ phænomina of Nature?
A. They are those appearances which occur in y^e^ natural World & not depending on the volition of an intelligent being.
Q. What is a law of Nature?
A. It is a fixt & invariable rule, by which the same causes always produce the same effects in y^e^ same circumstances.

A catechism of natural philosophy seems almost childlike today, but one might wish that all college students now knew by heart the following question and its multiple-barreled answer:

Q. What are the rules of philosophising?
A. 1. That more causes of natural things are not to be admitted than are both true & sufficient to explain y^e^ phænomina.
2. Of natural effects of the same kind the same causes are to be assigned as far as can be done.
3. The qualities of natural bodies which cannot be increased or diminished & agree to all bodies upon which experiments can be made are to be accounted the qualities of all bodies whatsoever.
4. Propositions collected from the phænomina by induction are to be deemed (notwithstanding contrary hypotheses) either axactley [*sic*], or very nearly true, till other phænomina occur by which they may be rendered more accurate or liable to exception.

These introductory Newtonian principles fill 15 pages, and are followed by separate sections on "Magnetism," "Electricity," "Gravitation," "Motion," "Mechanics," and these by five other sections—"Motion" (which develops the for-

mula $S=TV$), "Motion in resisting mediums," "Motion on inclined planes," "Pendulums," "Projectiles."

The last page filled by the unknown student is a poem that hardly bears on natural philosophy, but rather on moral philosophy—of the lower Epicurean sort:

Whatever *is* is right—POPE

When at Eve from home I ramble
In pursuit of Mirth & joy
Spend a trifle drink & gamble
Where's the harm in that my Boy?

Warm'd by Wine my blood quick flowing
Softer thoughts my mind imploy
Every Vein with rapture glowing
Sure no harm's in that my Boy.

With some yielding Nymph when lying
Tasting Love without alloy
In her Arms most sweetly dying
Say what harm's in that my Boy?

Give me then the Girl whose beauty
Kindly may all care destroy
Then if I neglect my duty
Say there's harm in that my Boy.

The other book is a fat volume of 538 pages published in 1809, *A Plain Elementary and Practical System of Natural Experimental Philosophy; including Astronomy and Chronology*, "by the late Rev. John Ewing, D.D., Provost of the University of Pennsylvania." Unlike modern textbooks, this first edition contains a flattering biography of the deceased author, which includes lengthy extracts from the sermon preached at his funeral and emphasizes his piety quite as much as his scientific achievements. The text itself is clearly an elaboration of what had appeared in the student notebook twenty years before. Presumably the content was sound science in its day, and its introduction is valid even now, for it is an eloquent appeal for the growth of the inquiring spirit and the scientific attitude. One sentence is especially interesting because it suggests what is somewhat more poetically expressed in Tennyson's "Flower in the Crannied Wall":

> There is more in a single vegetable, than has yet been adequately accounted for by the ablest philosopher that ever lived.

Still another many-sided scientist connected with the University of Pennsylvania during its early years, a polymath though not a polymathean professor, is David Rittenhouse. Although he never held the position of Professor of Natural Philosophy, he deserves mention here because during the first years of the College of Philadelphia he was in charge of the "philosophical apparatus." This must have been extensive, for on the establishment of the College one of the first acts of the trustees was to set aside £150 for equipment for experiments, and that was continually being added to—for instance, by the purchase in 1773 from the widow of Ebenezer Kinnersley of the latter's electrical apparatus, said by Rittenhouse to be the equal of any of its kind in the world. Rittenhouse was also appointed Professor of Astronomy in 1779, and no doubt would have been named to the chair of natural philosophy but for its already being filled by Doctor Ewing.

A full-scale biography rather than a few paragraphs is needed to do justice to this remarkable man, who with virtually no schooling at all attained scientific recognition equaled only in his day by Benjamin Franklin. Furthermore, his scientific achievements were largely based on a knowledge of mathematics, self-taught, to which Franklin could not pretend. Before he was twelve, it is said, he was devouring Newton's *Principia* and shortly thereafter he built his first clock, a contrivance with three wooden wheels. While still a boy, he would rest his plow-horse and mark with soapstone on fence posts the solutions to mathematical problems that occurred to him in the middle of the furrow.

By 1769, when he played a principal part in the observations of the transits of Venus and Mercury, his fame as a clockmaker, instrument maker, engineer and mathematician was established. Indeed, two years before, the College of Philadelphia had granted him an honorary M.A., the authorities "being well assured of the extraordinary progress you have made by a felicity of natural genius in mechanics, mathematics, astronomy, and other liberal arts and sciences." And two years later, in 1771, he was elected secretary of the American Philosophical Society, of which he became president on the death of Benjamin Franklin.

His practical accomplishments included the settling of boundary disputes between four pairs of states, the surveying of the Delaware River and surrounding country for fortifications and laying out of forts when he was Vice President of the Council of Safety during the Revolution and the casting and rifling of cannon. While experimenting with telescopic sights for rifles, he was nearly blinded. But even such activities during the War did not end his interest in the purer kind of science. As soon as the British had left Philadelphia, he returned and within a week was busy with William Smith and James Biddle in making the first really scientific observations in America of a solar eclipse.

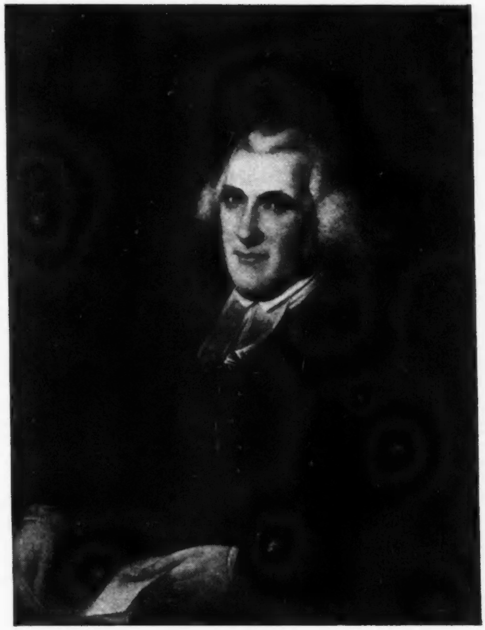
Something of his reputation at this time is revealed by a long letter from Thomas Jefferson, dated July 19, 1778, in which Jefferson, who later was to succeed Rittenhouse as President of the American Philosophical Society, regrets that the eclipse could not be seen in Virginia, hopes that Rittenhouse's instruments suffered no harm from the British, and suggests that the Philadelphia "philosopher," who for the preceding two years had served as treasurer of Pennsylvania, should let others devote their time to the drudgery of government, for "the world has but one Rittenhouse."

This letter especially expresses admiration for the mechanical planetarium or "orrery," as it was misnamed, that Rittenhouse had built. With a fine flourish of eighteenth-century skepticism and rhetoric, Jefferson wrote:

> The amazing mechanical representation of the solar system which you conceived & executed, has never been surpassed by any but the work of which it is a copy. . . . Without having ascended Mount Sina [*sic*] for inspiration, I can pronounce that the precept, in the decalogue of the vulgar, that they shall not make to themselves "the likeness of any thing that is in the heavens above" is reversed for you.

Although not so spectacular in its operation as the present optical devices, the instrument, which was accurate over a period of 10,000 years, was a striking enough example of the exquisite craftsmanship of its maker combined with unusual mathematical and astronomical knowledge.

Rarely has there appeared such an inquiring mind. From 1780 to 1796, although busy with arduous public work, he found time for experiments and inventions many of which he described in scientific papers that appeared on an average of one a year. He was the first to use spider threads as cross hairs in a telescope. He invented a collimating telescope, a wooden hygrometer, and a metallic thermometer, something for which Breguet received great credit a century later. He made a "Fraunhofer grating" before Fraunhofer was born. He developed a method of directly computing logarithms and discovered independently Wallis' formula for integrating powers of trigonometric functions. He experimented with optics, optical illusions and magnetism. It is not generally known that a paper of his, presented before the American Philosophical Society in February, 1781,[1] contained a concept of molecular magnetism similar to what was set forth in Coulomb's seventh *Memoir* in 1789 and elaborated by Poisson in 1824. And with it all he found time to manufacture clocks and scientific



John Ewing, D.D., second Provost of the University of Pennsylvania and Professor of Natural Philosophy. He was best known as a mathematician, astronomer and engineer, but he was also thoroughly acquainted with Greek, Latin and Hebrew, and from 1759 until his death in 1802 he was the pastor of the First Presbyterian Church in Philadelphia.

[1] Trans. Am. Phil. Soc. 2, 178–181 (1781).

instruments, to serve as the first director of the United States Mint and even to translate works of German and French literature.

The varied accomplishments of such a man make one wonder whether the youth of today suffer from too much or too little college education. Perhaps one type of "educator," of the very vociferous and unfortunately influential sort that deplores the teaching of mathematics beyond arithmetic, might find in Rittenhouse's career proof that earnestly scientific education is needless. But the conclusion would be unsound, for the youngsters who cannot face in school any subject without its being "motivated" to a degree of complete emasculation would hardly put themselves through the ordeal of self-instruction undertaken by Rittenhouse, and even by the two other scientists discussed here, Provosts Smith and Ewing. And on the other hand, the accomplishments of such men as these may also serve as an object lesson to those of today's specialists who, having taken charge of some little barony of knowledge, learn more and more about less and less.

War Problems of the Physics Teacher*

Arthur H. Compton
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IN presenting today the first Richtmyer Memorial Lecture we are doing honor to a physicist who was more than a physicist. He trained men who are now among the nation's leaders. His teaching enabled his students to acquire the technic of exact thinking. He had that breadth of vision which helped both his students and his colleagues to understand the setting of their scientific labors and to form intelligent objectives as their goals. He thus helped to lay the foundation of a strong society.

Those of us who had the pleasure of working with F. K. Richtmyer learned to admire the straightforwardness of his thinking, the courage with which he attacked new problems, and his reliability which gave us confidence that tasks assigned to him would be well done.

Today we have before us, as physics teachers, problems that are presented by the war. Some of these problems are new, others old. Richtmyer was a leader among those physicists who were concerned with the best use of our science in strengthening the nation. He knew that without the technical knowledge supplied by physics neither our industries nor our defenses could compete in the modern world. He was himself one of those farseeing men who at the close of the last war encouraged the training in this country of a large and capable group of young scientists. Before his generation, though a few American physicists were doing good work, we were far behind our European contemporaries with regard to the number of well-trained young men. In the development of modern physical theories, the United States had played a meager part. It was the vision and encouragement of such men as Richtmyer that brought large numbers of our best students into the fascinating studies of radiation and atoms, the result of which has been to supply the skilled men and women who are now our greatest source of national strength.

The Physics Teacher's War Problems

What are the distinctive problems with which the physics teacher is now faced? Let me mention a few. (1) Should we encourage our students to keep at the study of physics? (2) In teaching our students, how should the content of our courses be altered to meet the present emergency? (3) How can our methods of presentation best be adapted to present needs? (4) In a day when physics research is essential to the national defense, what should be the relative emphasis in

* First Richtmyer Memorial Lecture of the American Association of Physics Teachers, presented before the Association and the American Physical Society, at Princeton, December 30, 1941. Because it is desirable that scientists other than physicists also be acquainted with many of the ideas expressed in this paper, the editors of *The Scientific Monthly* have been granted the permission which they requested to publish this paper concurrently in that periodical.—The Editor.

our own work between our teaching and our technical investigations?

The broader problems also are insistent. How can physics best aid in building the nation's strength? What will be our situation when the war is over? Will our science continue to mold the development of society during the next generation as it has in the past? Let us consider these questions in order.

Should Students Study Physics in Time of War?

I believe the statement that in this war a hundred physicists are worth a million soldiers originated in England, when it was found how important the physicists were in meeting the threat of magnetic mines, of night bombers, and of submarines. This striking statement, on calm reflection, is hardly exaggerated. It applies especially to our American war effort, where at present our greatest contribution is in developing new devices for defense and offense and in supplying war materials that must be equal or superior to those used by enemies. If there is a threat of shortage of rubber, there is already an acute shortage of physicists. Thus nothing is more important in maintaining and building our military strength than the supply of an increasing number of well-trained physicists.

Emphasis on this point is being continually made in a series of editorials and articles in the American Journal of Physics. It is of first importance that attention to this need be kept before the students of physics, who are apt to become restless because of their desire to be of active service. It is of equal importance that our draft boards be kept aware of this situation, in order that our young men can be assigned to tasks in which their distinctive qualifications are useful.

In support of this view of the nation's need for physicists, let me refer merely to President Conant's report of the development of the Selective Service in Britain. He states that while, from the beginning of the war, men with scientific training were in a favored position, after the first year had elapsed, two groups—the physics and the medical students—were the only ones who were completely exempted from direct military training. This was because their professional service was so urgently needed that no time could be lost in completing their professional studies. It has become evident in the United States that a similar acute shortage of physicists is now beginning to show itself.

This, of course, does not mean that all persons who wish to study physics should be encouraged to go ahead. It is as true now as ever that it is the superior ones who can make the important contributions. This is especially true in the research field. There is, however, also the need for men and women having practical familiarity with physical instruments to do the laboratory and field tasks. These need not always be of the top rank. But we cannot afford to train numbers of inferior students at a time when our training resources are being strained. It thus becomes especially important for us to draw into the physics fold the most capable available young men and young women, and to weed out those whose promise is so low that their special training will be of little value to the nation's strength. Our college students should thus know of the nation's urgent need for high quality physicists, even though in view of the growing shortage of physics teachers we may need to enforce a stricter selection.

What Courses Should We Offer?

The answer to this question is that we need persons with all degrees of training. It is true, as it has always been, that the most valuable scientific men are those with thorough technical training combined with a broad knowledge of the relation of science to technology. Persons of these qualifications are, however, necessarily rare. We must remember that in many cases special training in particular fields of physics may considerably increase the value of persons who may be engaged upon defense tasks.

Among the special fields in which we are asked to train our students have been those of radio, meteorology and, in connection with the Civilian Pilot Training, the fundamentals of aviation. In these fields there are immediate applications. The present trend is apparently for more and more of the aviation training to be done directly by the Army. The more complete meteorology courses have been concentrated in a few centers, though there remains a place in

every college for introductory studies in this field. There would seem to be no adequate alternative, however, to the college training in the understanding and use of radio circuits. The demand for proficiency in such work must necessarily increase.

It remains true, however, as it has always been, that it is the fundamentals of physics which must form the basis of our instruction program. Without a thorough grounding we can supply to the nation only a half-baked group of physicists and eventually not only the students themselves but the nation as a whole will suffer. It may be complained that time is too short for such thorough training. To this the answer is that our struggle is not one of a year or two years; it is a struggle of a generation. At the moment we must rely upon those already trained for our scientific leadership. If, however, a continual supply of fully trained men is not available, it is inevitable that, as a nation, we shall decline.

In the preface to his book, *Introduction to modern physics*, Richtmyer presented his view of the importance of a thorough understanding of the background of physics.

> The author [in his teaching of physics] has attempted to present such a discussion of the origin, development, and present status of some of the more important concepts of physics, classical as well as modern, as will give to the student a correct perspective of the growth and present trend of physics as a whole. Such a perspective is a necessary basis—so the author, at least, believes—for a more intensive study of any of the various subdivisions of the subject. An account of modern physics which gives the *origin* of current theories is likely to be quite as interesting and valuable as is a categorical statement of the theories themselves. Indeed, in all branches of human knowledge the "why" is an absolutely indispensable accompaniment to the "what." "Why?" is the proverbial question of childhood. "Why?" inquires the thoughtful student in classroom or lecture hall. "Why?" demands the venerable scientist when listening to an exposition of views held by a colleague.

It is only upon those with this thorough grounding in why things happen that we can rely for our future scientific leadership. Rather than to omit such thorough studies, should not the effort be made to encourage our students to redouble their efforts to complete their college and graduate training as rapidly as is consistent with thoroughness?

New Methods of Presentation

There never was a time that called for more skill and care in teaching than now when the student's and teacher's time is precious. Presentation of our material in a form that can be clearly and quickly grasped is our part of the common task. Fortunately, the increasing familiarity of our students with mechanical and electrical devices is a help. The importance of physics in the war is likewise an asset in favor of the student's interest. We can call attention to the fact that success in his task is essential if a student would play his part in the national war effort, and that such success is measured by his classroom achievement.

The war supplies us with many devices that illustrate the principles of physics. It is clear that we shall want to make good use of these examples.

Teaching *versus* Research

Each of us at this time is asking himself, "At what task will my effort count for most?" Many who have been in our classrooms have become research physicists, or engineers, or physicians, who in their everyday service make use of what we have taught. To others, our instruction has, we hope, opened a broader understanding of the world, and an appreciation of the scientific method of thought. Through all of these students, the physics teacher can pride himself that he has contributed to the nation's strength. There is, however, the natural yearning by each of us to do something directly, and a dissatisfaction with what seems to be a routine job.

Is not the answer to this problem that, in whatever physics task we find ourselves engaged, we can be confident that we are contributing to the total strength of the nation? We want, naturally, to assure ourselves that our task is an essential one; but who would say that the physicist who develops an important application of electric waves that may be useful in war communication is performing a more valuable function than the man who trains the physicist who can do this and a thousand other tasks. Some physics teachers will be qualified for specific problems of research. They are fortunate. We shall give them all possible aid. If they are,

however, drawn from their classrooms, their places will need to be filled by others who may have different specialties. All of us will need to work at maximum capacity.

Physics and the Nation's Strength

It is not necessary to elaborate upon the many ways in which physics can be applied to the national defense. The demand for more physicists speaks for itself. Others can tell better than I what is being done. Much of the story must wait until the war is over.

Let me note, however, that urgent as is the present emergency, our task is to strengthen the nation for many years to come. We are confident of victory; but win or lose, the struggle will continue for decades, perhaps generations. For rival ideas, as well as rival armies, are at war. Defeat of the Axis armies will not mean that the national gods are destroyed, that nations will no longer seek prosperity by trying to enslave their neighbors. It will remain necessary for those who work for human welfare to demonstrate that in a free society useful knowledge can grow and can be directed to the common good.

The vaunted efficiency of the totalitarian regime has at least supplied us with an example of how not to prepare for the future. In 1939, before the war, in its concentration of effort on building a war machine, Hitler's Germany virtually eliminated theoretical physics from university instruction, on the ground that it was useless for the country's fighting power. Because of the demand for military service, the number of students of technical physics had fallen to a fourth of its peacetime level. Already at that time the shortage of technical men was felt, and training was retarded. One can hardly imagine that this deficiency has been rectified in the last two years. The result is inevitably a future Germany that will be at a disadvantage in technology when compared with its neighbors, unless after the war technically qualified men should be imported on a large scale.

By contrast, it is clear that if America wishes to maintain leadership in a society based on technology, the continued and increased training of physicists is essential. In time of meat shortage we must grow more cattle, not kill off those we have. When physicists are scarce we must intensify our training program. Those of us who remain in the colleges must, perforce, do double duty; but it will be a national calamity if our numbers are so greatly reduced that adequate teaching cannot be carried on.

What Lies Ahead for Physics?

The students that we train ask us, "What of our future?" They remember the depression, when physicists were unwanted. Now they see an intense demand. Some will be employed in the war, but many cannot expect to complete their preparation before the war is over. Then what?

You will recall that after World War I our universities doubled their enrolment. This was because the value of education had made itself evident to all the young men who were in the fighting. Chemical industries, newly established to meet the stoppage of German exports, drew thousands of young men. The close of that war meant the beginning of a new opportunity for America's chemists and engineers.

How then after the present war? President Conant, himself a chemist, remarks that this is the physicist's war. Never before has physics been in so favorable a position to demonstrate its effectiveness—and the demonstration is impressive. The outcome of this work must necessarily be the introduction of more physical technics in industry. Leaders in the current developments will be found in high places. As chemists in industry now seek young chemists to do new jobs, so as more physicists assume leading industrial positions, we may expect more young physicists to be called for. At the moment, at least, the trend is toward further emphasis on the physicist's role.

There is, of course, the possibility—some say the inevitability—of a postwar depression. If this should occur, my guess would still be that the physicist will feel such a depression less than those in other professions, for the reason just given, that our work is playing a rapidly growing part in the nation's life.

Professor Sarton tells how the continual growth of science forms the main line of man's gradual development toward more complete humanity. The growth of physics through which we are living is a clear example. We learn the laws of

heat and of electricity, and steam and electric power transform our world. We discover electrons, and the radio broadens our outlook. Nuclear physics takes its place, and dreams of a life based on atomic power arise ever more clearly before us.

To make use of these developments, society must become more highly organized. We depend upon one another more and more as our work grows more specialized. Willingness to work together is needed in the new society. Modern physics thus forces man to become more completely a social being.

It is a corollary that disorganization creates greater havoc now than in a pretechnical society. Our national strength grows greatly as we unify ourselves to meet a threat from without; but a world disorganized by war cannot function smoothly, and all mankind suffers. The science which leads toward a unified world thus makes war a greater disaster. It is such a threat that must make men learn to solve their problem without war.

According to ancient legend, Daedalus with his newly invented forge fashioned a steel sword which he presented to King Minos. "Alas," said the people, "this sword will bring us not happiness but strife." "'Tis not my purpose to make you happy," replied Daedalus, "but to make you great."

Thus it is that physics, giving vast new powers to man, is challenging him to shape his world on a more heroic scale. It is great to be a physicist in days like these. God grant that men may learn to use wisely the mighty sword that Daedalus gives.

A Physicist's Peace

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THIS is being called a physicist's war. The physicists are being called upon to devote themselves, and they are devoting themselves, to the design and development of devices to help our army and navy win the fight for freedom.

There is no use contemplating the alternative to victory. One abhorrent glance at humanity degraded to slavery is enough. We must and will prevail in the conflict in which we are engaged. Of our ultimate military victory there is not the slightest doubt, in view of the comparative resources of the opponents. But let us be equally sure of victory in the peace—victory for the principles for which we fight in the world struggle today.

What, then, do we fight for? We fight for a world organization of society in which a maximum of human effort is available and effectively used for improvement of the physical, mental and spiritual well-being of all mankind. This calls right now for the destruction by force of those who have made this war for an opposite purpose—the utter degradation of all mankind to the service of the conquerors. The struggle will not be easy, but in it we shall learn many valuable lessons. We shall learn to work together, and we shall learn our strength when united in a worthy cause. We shall learn the joy of tremendous effort and sacrifice. We shall learn enough so that never again will it be necessary to go through a period of dull, stupid, enervating stagnation such as we experienced in the 1930's.

After the enemy's will to conquest has been broken, then our real battle begins. Great areas will have been devastated. Even today some of the battlefields of the first World War remain unreclaimed. Men will be battle-scarred and weary. Spiritual force will be at low ebb. We shall all feel like relaxing. But this we must not do!

In the first place, let us be clear about the fact that there will be an abundance of important work to do, more than ever before. Even in America—richest nation in the world—vast millions of our people are today undernourished, improperly housed and inadequately clothed. Think then of the enormous task that lies ahead in bringing to all mankind merely the material benefits which a small fraction of the people

enjoys today. Let us not betray the heroes of this war in the peace. Let us make a pledge to continue the struggle for human betterment after the last shell has been fired—and with the same fierce earnestness that men are now displaying in defending their homes against the invaders. This Battle of the Peace shall be the most glorious adventure of the human race. Every man, woman and child in the world shall devote himself to it. The world's national and racial groups shall strive in keen and wholesome competition for the honor of making worthy advances and to help other less fortunate groups to go forward.

To win this battle completely we shall have to make many changes in our ways of life. We shall need to evolve a world political organization with power to maintain a society free from disturbance by aggressor groups. This is not nearly so difficult as many people suppose—given that we clearly understand our purpose and act accordingly. How much easier it would have been to stop Hitler in 1934 than now!

As citizens of a democracy we must mold our political organization to the form most suitable for the task ahead. The political solution resides, I am sure, in a close union of the allies now resisting the aggressors on a basis that provides for the gradual extension to all mankind of the liberal forms of democratic government of our own Constitution.

We shall learn to apply the rational methods of scientific investigation and experiment to the problems of political and economic management. We shall insist on a much larger public support of scientific research than ever before—not in the petty spirit of augmenting the private position of the scientists, but in recognition of the importance of research to the accomplishment of our goal. Instead of a NDRC we must have a vigorous and flourishing WPRC—World Progress Research Committee.

We shall face an enormous task in re-educating a whole generation of Germans, Italians and Japanese whose orientation at present deprives most of them of understanding the ideals for which we are fighting. This will have to be worked out by a mass program of occupational therapy in which these unfortunate individuals are given an opportunity to labor at reconstruction of the devastated areas, under conditions which will also open their hearts to an understanding of that for which we fought. This reconstruction, including the physical act of carrying back the loot they have taken from the invaded countries, will keep the Nazis busy for a long time—and definitely out of mischief if properly supervised.

Such a program for the peace will find physicists able to serve in a way that will entitle them to a place of honor. It is they who are charged with the duty of gaining as completely as possible a rational understanding of the physical forces of nature. Moreover, it is their additional duty to transmit this information to others who will put it to use in improving the physical well-being of all mankind.

The educational program we shall face is colossal. There has already been a hideous destruction by the Nazis of scientists, and of libraries and scientific equipment in Europe. There has everywhere been a terrible interruption in the training of scientists. And anyway, the number of persons who were trained in science before the war is now known to be totally inadequate for the work of the future.

It is entrusted to us to determine the future of mankind for a long time to come. Let us therefore work together with all men whose minds and hearts are ready: "With malice toward none, with charity for all, with firmness in the right as God gives us to see the right . . . to do all which may achieve and cherish a just and lasting peace among ourselves and with all nations."

It is most wretched always to be using what has been attained, and never reach further for one's self.—ROGER BACON.

The Role of Laboratory Work in the Early Years of the Engineering Curriculum

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Within recent years the traditional laboratory work in the freshman and sophomore years of the basic sciences has been subjected to rigorous scrutiny on the part of administrators (and others) with regard to its essential value in the educational program. In some instances there has been a movement to curtail laboratory work, or even eliminate it, and to supplant it with group demonstrations, science museums and other methods of predigested instruction. In this connection, let it be said that all of these teaching aids are recognized as having their peculiar values, and the present contention that these devices are inadequate substitutes for laboratory work in engineering courses is not to be construed as a condemnation of them as legitimate teaching methods in their proper places. This paper is concerned with the essential value of laboratory work in the early years of the engineering curriculum and with the considerations that influence that value.

Those who question the value and efficiency of laboratory work do so on two grounds. The first, of course, is economy—economy of space, time, instructional cost and capital investment.

It is true that the per capita cost of instruction is relatively high in the physical sciences, largely on account of the teaching time required in the laboratory and the large capital investment involved. This is a situation against which the science teacher always has to contend, unless he has the rare good fortune to be associated with an administrator who thoroughly understands the problem. For example, the per capita floor space required for laboratory work in physics is, by virtue of the nature of the work, greater than in any other elementary science. Corresponding sources of expense are found in all of the elementary sciences. The question is: Can the additional cost of laboratory work be justified on the grounds that it is an essential part of the science course? It is the present contention that, insofar as the training of science majors and engineers is concerned, the answer is an emphatic "yes." Subsequent arguments in this paper will attempt to justify this claim.

The second contention of the opponents of laboratory work is based on student interest and profit. It is frequently maintained that students enjoy the demonstration lectures and profit from the quiz discussions but are hopelessly bored with the long and tedious hours in the laboratory. It is contended that the meticulous routine of the laboratory contributes little of permanent value and often kills any interest that may be stimulated by a skilled lecturer. In seeking to evaluate such claims, one must be careful to do so for a specific class of students, and to keep continually in mind the objectives of the course for the particular student group in question. Thus, there may be some justification for a minimum amount of science laboratory work for students of nontechnical subjects, such as speech, journalism and music, for whom the values in the basic science courses are mainly cultural. This situation has been recognized for several years, and many forms of so-called "orientation courses" have been planned to meet this need. In advocating the extension of this type of program to other basic science courses in technical fields, administrators frequently confuse the learning of basic essentials and their interrelationships with "learning about" a subject. Often a superficial knowledge of a science gives the student little more than a glib vocabulary and a delusion of having mastered the essentials of the subject. While this would not perhaps be serious for the nontechnical student, it would be fatal for the student of science or engineering. These students must have a *working knowledge* of the basic sciences, for subsequent technical and highly specialized courses depend directly upon these sciences. For example, mechanics, hydraulics, steam and gas, and practically all of the electrical engineering courses are simply extensions of certain portions of physics. Consequently, a sound working knowledge of general physics is presupposed in these courses. Such a knowledge of an experimental science can only be obtained by supplementing the lecture demonstrations and the classroom discussions with rigorous experimentation in the laboratory.

Regarding the contention that long hours in the laboratory are irksome to the student, the experience of the writer is quite to the contrary. Our general physics laboratory work is conducted in weekly periods of four hours each. We prefer one 4-hr period to two 2-hr periods because we believe that, where the curriculum will permit of long periods, such a schedule makes more efficient use of the time. The more exacting and comprehensive experiments which are used with the engineers can usually be completed in a 4-hr period, whereas with two 2-hr periods, much time is lost in taking down and reassembling apparatus and in making a new start on an interrupted investigation. Frequently a student will tell us that when he enrolled in the course he had grave misgivings about the long laboratory period, but that he finds the time passes quickly and pleasantly. Certainly no ordinary recitation could be anything like as long, and even the most entertaining lecturer would be risking utter defeat if he attempted to hold a class for half that time. The engineers, especially, look upon the laboratory work as the most interesting, and often the most instructive, part of the course.

With respect to students of engineering, two significant facts may be stated: (1) the specific objectives of the engineering curriculum are known with a definiteness that is not exceeded, if equaled, with any other group of undergraduates; (2) the engineering students form as homogeneous a group with respect to background, aptitude and attitude toward their work as any that can be found. These two facts make it possible to speak with confidence regarding the role of laboratory work in the early years of the engineering curriculum.

A search of the literature reveals that, while numerous articles dealing with specific laboratory problems have appeared, there is a paucity of articles on the fundamental problem of the essential value of laboratory work for science and engineering students. The probable reason for this is the fact that the value of laboratory work is never questioned by scientists themselves; the need for it seems obvious to those engaged in the training of students in science and engineering. In all probability the majority of the readers of this paper are entirely sympathetic with the writer's point of view. Then why discuss the problem at all? There are two reasons for doing so:

(1) To crystallize our ideas and thereby become able to present the case for the laboratory sciences logically and convincingly;

(2) To take stock of our laboratory programs and see whether or not they are fulfilling their proper roles; and if not, so to modify them that they will fulfill these roles.

Obviously, the methods of instruction to be applied in any course depend upon the specific objectives of the course. The objectives of general physics in the engineering curriculum have been clearly set forth and ably discussed by Professor C. J. Lapp,[1] who lists the four major objectives of such a course as follows:

(1) A thorough mastery of the basis of general physics;

(2) An extensive knowledge of, and skill in using, the measuring instruments of physics that are useful to the engineer;

(3) Cultivation of the scientific attitude;

(4) Stimulation of the imagination and the creative ability of the student.

These objectives may be accepted (with perhaps slight modification) as applying to other basic science courses in the engineering curriculum.

The question which follows naturally is: In what specific ways does the laboratory part of the course contribute to these objectives? In answer to this question, the writer ventures to suggest five contributions of laboratory work and to discuss each briefly.

In the first place, the laboratory work contributes immeasurably to the student's grasp of the subject matter by bringing him into intimate contact with the factual material and the applications of the basic principles of the subject. It accomplishes what no end of textbook illustrations and blackboard drawings can do. It clarifies the essential physical conditions, the time and space relationships, the relative magnitudes of the quantities involved. A student of biology might have a thorough understanding of a section drawing of an amoeba and yet have no idea whatever of the size and environment of its physical counterpart. A student of physics could very well be familiar with the schematic diagram of the thermionic vacuum tube and possess an apparent understanding of the principles involved, but have a wholly inadequate concept of

[1] Lapp, "Teaching engineering physics," Am. J. Phys. **8**, 346 (1940).

the physical structure and operation of such a tube, to say nothing of being able to wire up the circuit for one and put it to actual use. Those who would replace active student participation in experimental work with lecture demonstrations and museum stunts fail to appreciate the important distinction between a working knowledge of a science and a superficial familiarity with the most spectacular phases of the subject. The science museum is a valuable asset to the laboratory but is in no sense a substitute for it. True scientific knowledge is not gained by the attitude embodied in the notorious slogan, "You press the button, we do the rest."

The claim is sometimes made that the same old experiments have been performed in the laboratory for many years and that the laboratory needs to be brought up to date—"streamlined," so to speak. Without wishing to discredit this idea entirely (for it certainly is true that a scientific laboratory must above all keep abreast of the times), still it is a fact that the great body of basic science changes slowly and that instruction must always be based upon a rather definite and permanent set of fundamental principles. Of course, equipment and methods must be revised from time to time to take into account new developments and refinements in the design and construction of apparatus.

The laboratory work can perhaps contribute most effectively to the basic training of the engineer when the selection of experiments is governed by the following criterions:

(1) The experiments should emphasize the most fundamental principles of the subject;
(2) For the most part they should deal with topics for which lecture demonstrations are not adequate;
(3) They should involve procedures, analyses and the use of instruments that are closely coordinated with the engineer's later practice.

A second important contribution of laboratory work in physics is the development of manipulative skill. The ability to set up an experimental investigation and carry it out skilfully is one of the engineer's first qualifications. The engineer must be an experimenter. Skill and originality in the manipulation of equipment is not achieved merely by watching a skilful manipulator or by examining a finished product. Only through the devious and laborious routine of repeated trial and error in the laboratory can one cultivate the important ability to "make things work" that amounts almost to a sixth sense. In his paper Professor Lapp cites as one of the primary aims of engineering physics the acquisition of a knowledge of and skill in the use of measuring instruments. This is the unique province of the laboratory course. For the essential training and experience which the laboratory work provides in the handling of measuring instruments, there is no substitute. The only further remark to be made in this connection is that the apparatus and measuring instruments must command the respect of the student. While there may be something to be said for the "nail and string" type of apparatus in elementary laboratory work for nontechnical students, the apparatus to be used in engineering courses should be the very best obtainable.

A third and very significant aspect of the laboratory work is the fact that it develops self-reliance and ingenuity. In lectures and recitations the thought processes of the student are under the constant guidance of the instructor, but in the laboratory the student has to proceed largely upon his own initiative and to depend upon his inventiveness to see him through. He must map out his procedure, coordinate the experimental details, organize the data and deduce his own conclusions. He learns to recognize places where his knowledge of background material is inadequate and to make up for the deficiency.

This leads to motivated study and develops individual initiative. Set two students to work together upon a laboratory project and their respective qualities of originality and leadership will immediately be apparent. If there is any educational system better than the Mark Hopkins ideal of an instructor on one end of a log and a student on the other, it is that of a student on each end of the log.

A fourth contribution of laboratory work to the engineering program is essential training in the interpretation of experimental data. Projects should be selected that will present varied analytic and graphical methods of treating experimental data, estimating probable error and deducing conclusions. For the engineer this is a very practical and essential training. A most valuable aspect of the laboratory work in physics

is the opportunity that it presents for the use of graphical methods. In addition to a great variety of relationships represented by Cartesian graphs, numerous applications of logarithmic and semilogarithmic graphs are found, and no opportunity to employ them should be lost.

In most of the traditional experiments designed for training in the interpretation of data, the object is the experimental verification of a previously formulated mathematical relationship. Without questioning the essential value of this type of experiment, the writer ventures to suggest that, at least in engineering courses, more experiments than we now have should be devoted to the objective of deducing empirical equations.

As an example, the sophomore experiment on the flexure of a beam can be approached equally well in either of two ways: the expression for the deflection of the beam in terms of Young's modulus for the material and the dimensions of the body may be derived theoretically and the various relationships then demonstrated experimentally; or, an empirical equation may be formulated from semilogarithmic graphs of experimental data. The practical value of experiments of the latter type justifies the inclusion of some of them in engineering courses.

Fifth and last in this list of contributions that the laboratory work makes to undergraduate engineering courses is the cultivation of scientific attitudes and an appreciation of scientific methods through experimental investigation. This contribution is no less real because it is less tangible than the others that have been mentioned. The very bases of physical methods are controlled experimental investigation and impartial analysis of data. While numerous interesting and fascinating illustrations of the scientific approach to a problem may be cited from the voluminous pages of scientific history, these examples have little, if any, direct effect upon the behavior of the student. When, however, the student is confronted with a problem which he himself must solve with the aid of physical equipment, scientific methods assume real significance and his point of view and behavior are more likely to be influenced by these personal experiences. It is in this connection that teachers of the laboratory sciences need most searchingly to scrutinize their laboratory practices. It cannot be assumed that *all* laboratory work, merely because it involves experimentation, *necessarily* contributes to the cultivation of scientific attitudes. In order to achieve this supreme end, the experimental projects must be planned and presented with such an objective definitely in mind. This requires thorough investigation of the full possibilities of each individual experiment and thoughtful presentation of the project to the student. By careful selection of material and judicious adaptation of it to the needs of the particular student group involved, the laboratory work can be made to have a profound influence on the student's point of view in a science.

In conclusion, let it be said that experimentation is the very touchstone of scientific progress. While natural experimenters may be born to science, they must also be trained in her unique and highly specialized methods. The foundation of all this is the student laboratory work in the basic sciences.

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The New Physics Building at The Pennsylvania State College*

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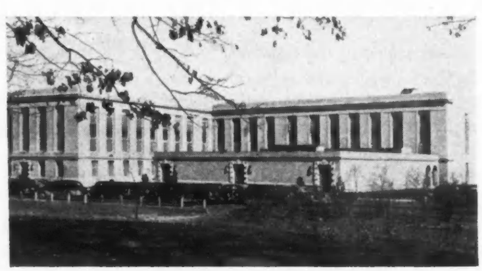
THE new physics building of the School of Chemistry and Physics of The Pennsylvania State College justifies a rather complete description, not only because of the building itself, but also because of the way in which the final building plans were achieved. In 1936 the physics and chemistry departments together occupied all of five separate buildings, the astronomical observatory of the physics department was housed on the top of a sixth building, and both departments used classrooms wherever they could be obtained on the campus. The departments were growing so rapidly that they were continually overcrowded. The pressure for additional space for physics laboratory instruction and research finally became so great that the head of the physics department, Dr. W. R. Ham, appointed a departmental housing committee with written instructions to "find what space and facilities were needed, by whom they were needed, and why they were needed; and if possible, arrange for getting them." In a separate letter, he instructed the committee that its decisions were to be final and not subject to review even by himself. The successful work of the housing committee has been largely the result of these farseeing instructions.

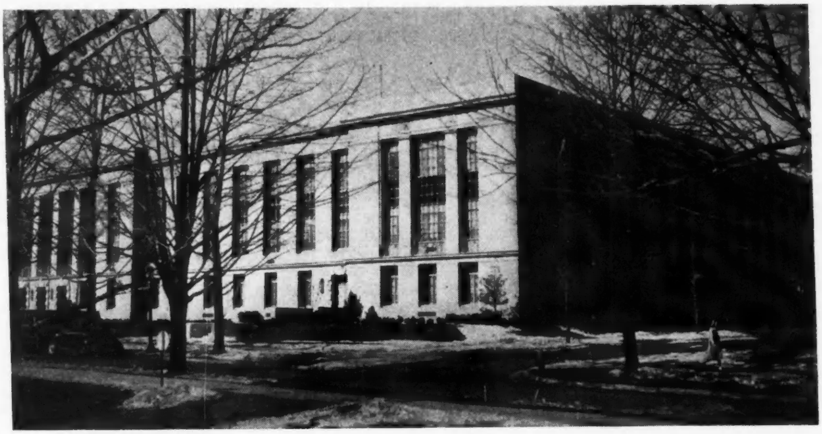
The housing committee had been in existence a few weeks and had barely got started on its work when it heard rumors that Federal and state funds for new buildings might possibly become available through the General State Authority. With the consent of Dean F. C. Whitmore, the housing committee of the physics department and Dr. G. C. Chandlee, head of the chemistry department, agreed that the two departments would present a united front on the following outline of policy: if a building program should materialize for the School of Chemistry and Physics, (1) the first new building should be a physics building; (2) the second new building should be for the chemistry department; (3) certain space in the proposed new physics building should be made available to the chemistry department until such time as the second new building could be obtained. Dean Whitmore at once added a representative of the chemistry department to the committee and made it a School committee. This enlarged housing committee, then, represented both departments in all planning for the new physics building and its equipment.

The committee at once asked every man on the physics staff who was at that time in direct charge of some part of the work of the department to submit (1) a floor plan, drawn to scale, of the space which he felt he should have in order to do his work best; (2) elevations to scale of all walls for (1); (3) indications on (1) and (2) of all gas, air, hot and cold water, sewer, steam, a.c., d.c., and other services, showing their type, number and exact location; (4) outlines on (1) and (2) of all cupboards, tables and other furniture needed as of the date of making the drawing, together with a statement for each



Rear view of building.

* This article is one of a series designed to acquaint readers with the equipment and facilities at various institutions and to make available information that should be helpful to departments in planning a new or remodeled building. Articles previously published are: G. R. Harrison, "Spectroscopy at the Massachusetts Institute of Technology," **1**, 109 (1933); S. L. Brown, "New physics laboratory at the University of Texas," **2**, 70 (1934); C. F. Hagenow, "New physics building at Washington University," **3**, 25 (1935); L. M. Alexander, "Physics laboratory at the University of Cincinnati," **3**, 123 (1935); L. S. McDowell, "Physics at Wellesley," **4**, 57 (1936); F. O. Severinghaus, "Physics wing of the new science building at Brooklyn College," **7**, 130 (1939); W. C. Michels and A. L. Patterson, "Remodeled physics laboratory at Bryn Mawr College," **8**, 117 (1940); W. L. Kennon, A. B. Lewis, S. C. Gladden and M. W. Hodge, "Physics building project at the University of Mississippi," **8**, 294 (1940); J. W. Buchta, "Physics laboratory at the University of Minnesota," **8**, 375 (1940).—THE EDITOR.



Front view of building.

item as to whether it was already available or would have to be acquired; (5) an itemized list of the equipment for which, as of that date, the tables, cupboards and furniture were intended, together with a statement as to whether or not each item was already available; (6) a complete statement of the reasons why each item in (4) and (5) was needed, and an indication of the degree of urgency of that need. Similar requests were made of the men designated by the head of the chemistry department to have space in the proposed building. In this way, the instrument maker designed his own shop, the stockman designed the stockrooms, the men in charge of various types of research designed their own research laboratories, the man in charge of sophomore instruction in physics designed the sophomore laboratories, and so forth.

Obviously, the information gained from (4), (5) and (6) was obsolescent the day it was received, but at least it made sure that each man had considered his needs minutely *as of some one date*, that he had considered carefully in what terms he could justify his statement of needs, and that he had a chance to present his case *as of that date* before a competent, impartial, but sympathetic tribunal. It is a tribute to the conscientious work of the many staff members concerned and to their sense of proportion that the housing committee found it advisable to revise the requests of only two men—one upward (his request was considered too modest in terms of his proved ability and past performance), and one downward (his request could have been amply justified under other circumstances, but it involved more space and equipment than the committee had reason to believe might be available).

The housing committee contributed the idea of putting acoustic plaster on the ceilings of all halls, offices, shops, lecture rooms, classrooms and undergraduate laboratories, and the idea of having vertical ducts on each side of each hall, extending from the basement floor to the attic and running the full length of each hallway. The committee also provided ten classrooms and two lecture rooms on the first floor and a minimum of offices.

With the generous aid of the college Department of Grounds and Buildings, these individual plans were assembled into tentative plans for a building. Thanks to the active and sympathetic cooperation of the architects, the housing committee was able to fit a five-story building—three floors above ground and two below—around the physics department instead of having to fit the department into a building,[1] and at the same time to house properly that portion of the chemistry department which was to have tempo-

[1] The building as it stands does not quite completely house the physics department, which still occupies about 2500 ft^2 of research space in the Chemical Engineering Building and about 500 ft^2 in Buckhout Laboratory (botany). In addition to this borrowed space, the department has the first two out of a proposed nest of 12 instructional observatories situated at one end of the campus. These are 12×12 ft in size and are each intended for one or two students at a time.

TABLE I. Areas and volumes by use.*

	No. of Rooms	Area (ft²)	Percent of Total Area	Volume (ft³)	Percent of Total Volume	Heated Volume (ft³)
Academic use†						
Classrooms	11	10,978	8.0	111,711	5.6	111,711
Undergraduate Labs.	16	17,292	12.5	212,130	10.5	212,130
Graduate Labs.	21	26,898	19.4	327,150	16.2	327,150
Prep., Stock- and Accessory Rooms	21	6,367	4.6	67,980	3.4	67,980
Lecture Rooms	2	4,720	2.7	99,189	4.9	99,189
Photo. Darkrooms	2	853	0.6	10,240	0.5	10,240
Machine Shops	3	2,959	2.1	36,000	1.8	36,000
Faculty Offices and Conf. Rooms	11	2,662	1.9	32,550	1.6	32,550
General Storage	8	7,176	5.2	87,060	4.3	87,060
Departmental Library	1	1,090	0.8	13,280	0.7	13,280
Dead Storage and Space for Wind Tunnel	2	5,373	3.9	64,970	3.2	64,970
Administration and general						
General Offices	2	584	0.4	7,060	0.3	7,060
Private Offices	2	583	0.4	6,980	0.3	6,980
Mailing and Mimeographing	2	180	0.1	2,190	0.1	2,190
General Office Storage	2	160	0.1	1,950	0.1	1,950
Student Toilets	7	2,082	1.5	25,550	1.3	25,550
Faculty Toilets	1	245	0.2	2,980	0.1	2,980
Service and maintenance						
Mechanical Equipment	6	5,934	4.3	71,420	3.6	71,420
Janitorial	7	104	0.1	1,270	0.1	1,220
Projection Rooms	2	358	0.3	2,860	0.1	2,860
Circulation	—	21,966	15.8	244,650	12.1	244,650
Construction	—	21,885	15.8	587,804	29.2	——
Totals		138,659	100.0	2,016,974	100.0	1,429,170

* The areas by floors are: sub-basement, 17,336 ft²; basement, 35,821 ft²; intermediate, 2300 ft²; first floor, 33,960 ft²; second floor, 24,999 ft²; third floor, 24,243 ft². The total area is 138,659 ft², and the total volume, 2,016,974 ft³.

† This breakdown differs somewhat from that used in the body of the text, but the total number of rooms and the total areas and volumes devoted to academic uses are correct.

rary space in the new building.[2] The long-time usefulness of this unusual building is greatly enhanced by the fact that the general contractor and the various tradeswork and equipment contractors all were scrupulously honest in the performance of their work.

A few points in the design are worthy of specific mention. With the funds estimated to be available, it was evident that office space would have to be kept strictly to a minimum if sufficient space were to be provided for instruction and research. Modest offices were provided for the Dean of the School of Chemistry and Physics (rooms *122* and *123*) and for the head of the physics department and the departmental offices (rooms *101*, *101a* and *102*). Small offices (rooms *210* and *211*) were also provided for the men in charge of the sophomore laboratories and of the apparatus inventory. Each staff member in charge of thesis work was provided with suitable desk space for himself and his graduate students in his own thesis laboratory. The lack of conventional office space was, to some extent at least, compensated for by four small conference rooms (*107*, *108*, *121*, *218*), space for which was left over after putting together into one building the rooms that had been specifically requested. Two seminar rooms (*120* and *217*) were also provided which might be used for conference rooms when not otherwise engaged.

In order to avoid as much as possible the evils of "mass production" in dealing with the thousand or so undergraduate students who pass through the physics department each semester, the sophomore laboratories have been broken up into nine rooms,[3] each about 25×32 ft in

[2] The chemistry department has, in this building, 3 of its 6 freshman laboratories (rooms *301*, *302*, *310*), a thesis laboratory for the study of inert fluorine compounds (room *303*), 3 thesis laboratories for physical chemistry (rooms *204*, *304*, *306*), capable of taking care of about 8 graduate students, and a large laboratory (room *305*), which takes care of about 20 research students in organic chemistry. The department also uses class- and lecture rooms on the first floor and has considerable storage space (rooms *7* and *11*) in the basement.

[3] Of the ten laboratories originally planned for sophomore use, one (room *204*) was diverted to physico-chemical research.

size and designed to care for an optimum of 16 and a maximum of 20 students per section (rooms *201–3*, *206–9*, *212*, *219*). In addition to the customary laboratory tables, each sophomore laboratory is provided with 20 seats facing a blackboard so that students may be quizzed on the theories and technics involved in their experiments. Four of these sophomore laboratories are provided with darkrooms for elementary experiments on spectroscopy and photometry. Three laboratories (rooms *111*, *215*, *216*) are set aside for laboratories of junior-senior grade—heat, optics, electrical measurements, oscillation circuits.

In order that "the dead hand of the past" may not prevent changes when and if found desirable in the future, all wiring and piping is exposed in each laboratory. Each room is serviced from the 2-ft wide vertical ducts that line both sides of all halls. Access to these vertical ducts is obtained from the halls by means of a continuous system of Transite panels, so that all maintenance, alterations and extensions of services such as gas, air, water, steam, sewer, electricity and ventilation can be taken care of from the halls without disturbing the classrooms and laboratories. The idea of providing for an orderly expansion is evident in all parts of the building. For instance, at present all sophomore laboratories are on the second floor and all classrooms are on the first floor. All classrooms are made the size of the second floor laboratories so that, as the enrolment in physics courses increases, the classrooms can be converted one by one into sophomore laboratories. This will gradually drive the classroom instruction into other classrooms here and there on the campus until a west, classroom wing can be added to complete the building. In anticipation of this, an extra apparatus stockroom (room *114*) has been incorporated in the first floor plan to supplement the stockrooms (rooms *213*, *214*) on the second floor. At present this extra stockroom is used for the apparatus required by the extension (ESMDT) courses offered by the physics department.

Provision for the future may be found, too, in the general design of the third floor, which is now occupied by a portion of the chemistry department. When the time comes for the chemists to move out into adequate space of their own, it is planned that the present departmental library (room *205*) will become a sophomore laboratory and that room *301* will become the departmental library. Rooms *302* and *310* will become research laboratories. Room *305* can easily be broken up into four rooms, two for research and two for seminars. Rooms *303*, *304* and *306* will probably be used for research in physical chemistry and chemical physics.

On the first floor, situated behind the lobby at the main entrance to the building, are two air-conditioned lecture rooms, one with 150 seats and one with 350 seats. These have no windows, so that it is easy to darken them for showing lantern slides, optical experiments, and so forth. These lecture rooms have their own stockrooms for lecture demonstration apparatus. That some provision has been made for future growth of the stock of demonstration equipment is shown by the fact that these lecture stockrooms have about 2500 linear feet of shelving—an average of about 10 ft per lecture.

TABLE II. Cost data.

Item	Cost	Unit Cost per Cubic Foot of Total Volume
Preliminary	$ 142,297.72	$0.071
General contract	569,946.15	.278
Plumbing	85,211.12	.042
Heating and ventilation	58,744.60	.029
Electrical	47,507.06	.024
Landscaping	7,096.37	.004
Fixed equipment	187,575.34	.093
Total	$1,098,378.36	$0.541

The instrument maker's shop (room *2*) is equipped with two 11-in. precision "toolroom" lathes, a 20-cm precision lathe, a milling machine with five degrees of freedom in setting up the work, a shaper with four degrees of freedom, a 76×24-in. planer, a precision tool and surface grinder, a swaging machine, the customary accessories, drill presses, band saw, power hacksaw, welding equipment and work benches. Separated from the instrument maker's shop by a wire grating is the main student shop (room *1*). It contains one 9-in. and two 11-in. "toolroom" lathes, one 27-in. lathe, a miller, a shaper, two drill presses, a power hacksaw and the customary benches. Provision is also made for a small forge when needed. There are also smaller, highly specialized, student shops in such thesis laboratories as need them. A glass-blowing room

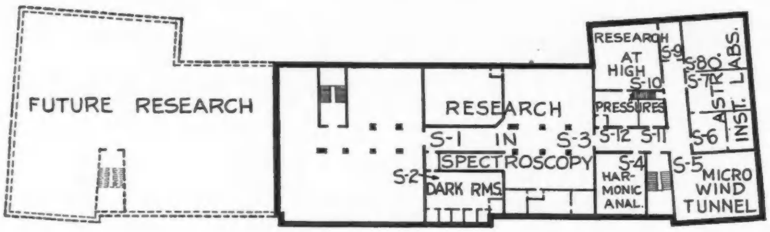


FIG. 1. Sub-basement plan.
|——100 ft——|

(room *10*) contains, besides the customary facilities, a glass-blowing lathe.

The thesis laboratories are enough different from the customary type to justify special mention. Instead of the usual rows of monastic cells, large laboratories are provided, each of which has been especially designed for research along one general topic. In this way, exceptional facilities can be made available to graduate students which would otherwise be quite impossible except at prohibitive expense. Each of these laboratories, then, serves a group of graduate students all working individually along allied lines, each constructing his own apparatus, but all using the general facilities of the large room in common. This scheme, patterned after that of many industrial laboratories, has turned out to be quite successful. Each man benefits from the experience of his fellows in the large room, and all have the possibility of constant advice and inspiration from their thesis supervisor, whose headquarters are in the same large room. It will be of interest to take up the various thesis rooms in more detail.

The spectroscopy laboratory (rooms *S-1*, *S-3*) situated in the sub-basement 25 ft deep in solid limestone rock, contains the following major items of equipment. A 21-ft concave grating of 15,000 line/in. is mounted in a Paschen mounting; this is a very perfect grating since it gives 90 percent of the theoretical resolving power in the fourth order. In the same darkroom with the 21-ft grating is installed a spectrograph which makes use of an 8-in. plane grating in a mounting between two parabolic mirrors, one of 12-ft focal length (collimator) and one of 32-ft focal length (objective). In a separate room an 8-in., 15,000 line/in., 15-ft concave grating is mounted in a Meggers and Burns type stigmatic mounting using a 90-in. focal length mirror as collimator. As auxiliary equipment for work at lower dispersion there are available a large three-prism glass spectrograph (effective aperture $f=4.5$) and a 1-m, 4-in. concave grating of 15,000 line/in. A constant amplitude photoelectric ultraviolet spectrophotometer of the recording type has been recently developed in this laboratory. It makes use of an 8-in. plane grating and has an aperture of $f=5$. The laboratory is also provided with its own photographic darkroom.

Room *S-4* contains a General Electric harmonic generator which gives, besides the fundamental frequency, the first, second, fourth and sixth harmonics. The phase and amplitude of each harmonic with reference to the fundamental can be individually adjusted. The room is not yet completely equipped since delivery of certain measuring apparatus has been greatly delayed.

A micro wind tunnel is being built in room *S-5*. It is intended to provide those fundamental physical data at 250 mi/hr that are necessary to give a sound basis for future airplane engineering work at ultra-high speeds.

An astronomical instruments laboratory (rooms *S-6*, *S-7*, *S-8*) has ample facilities for grinding and testing lenses and mirrors of diameters up to 10 in., and for aluminizing mirrors. A special shop is equipped for making telescope tubes and mountings. These facilities are regularly used in connection with instruction in amateur telescope making, but they are available for building special optical apparatus for other sections of the physics department. In this connection it is interesting to note that the two 10-in. telescopes and their Springfield-type mountings used in the college instructional observatory were made in this laboratory. The laboratory research equipment includes a Ross Fecker astrographic camera, a 3-in. Gaertner meridian circle, and two of what are believed to be the only four electrically operated sidereal clocks in the country.

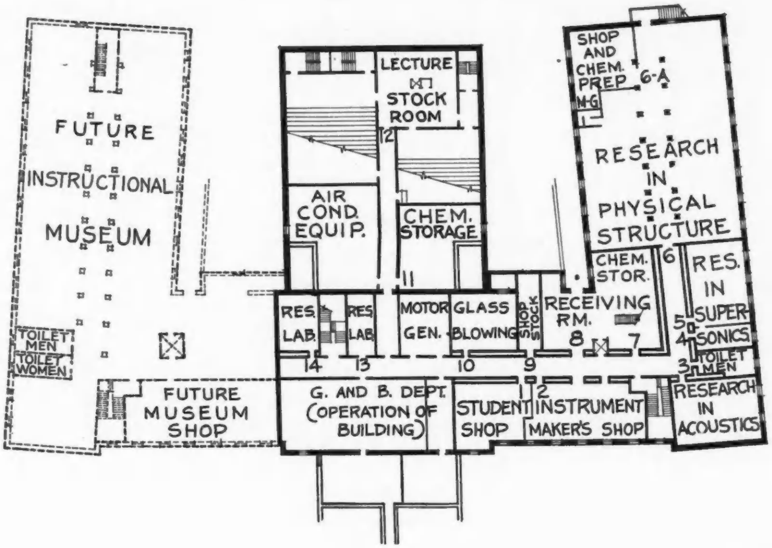


FIG. 2. Basement plan.

A laboratory for studying the effects of high pressures occupies four interconnecting rooms (*S-9, S-10, S-11, S-12*). The equipment includes the necessary pumps and gages for getting and measuring hydrostatic pressures up to a maximum of 450,000 lb/in.^{2}; containers suitable for measuring the biological effects of high pressures; thermostated absolute and relative viscometers adapted for use at high pressures; equipment for studying the effects of high pressures on various types of containers. This equipment is put in four connecting rooms of moderate size instead of in one large room to reduce the chance of contamination of experimental materials in case of a mechanical failure.

An acoustic laboratory (room *3*) is provided

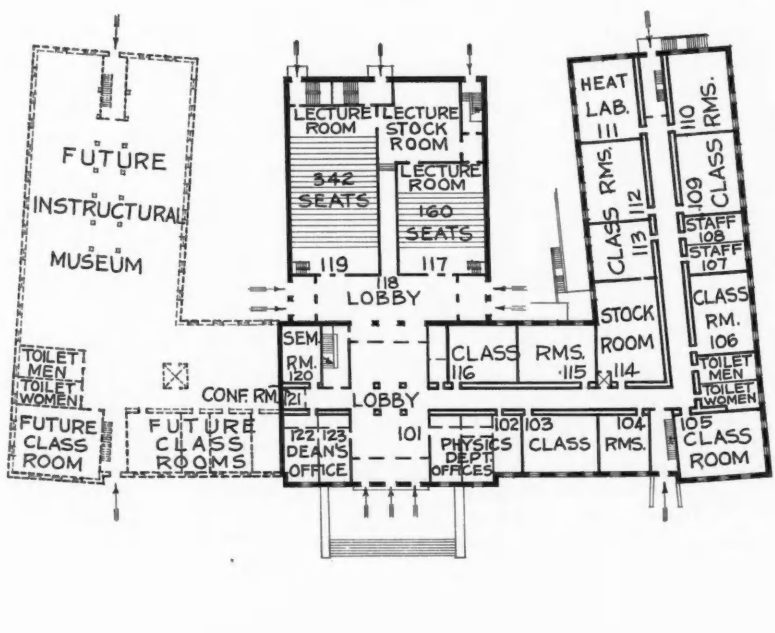


FIG. 3. First floor plan.

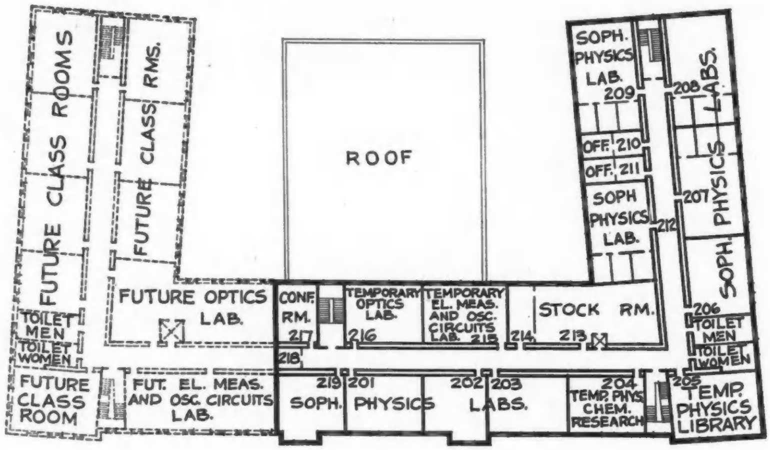


FIG. 4. Second floor plan.

with standardized sound sources, and with noise-level measuring instruments. This laboratory is not as yet completely equipped.

The supersonics laboratory (rooms *4* and *5*) is unique in that each of the two rooms is a grounded "Faraday ice pail." Before these two rooms were plastered and before the floor covering was laid, the walls, ceilings and floors were lined with tinned sheet iron. All seams were soldered and metallic connections were made to all doors (which are of metal) and to all window frames and screens. This metal lining is connected directly to wet ground in three places. The electric driving units, therefore, cannot cause outside radio interference. The laboratory is equipped with driving units for producing sonic waves of frequencies ranging from 40 to 3000 kilocycle/sec, and with sonic interferometers for use with various gases at various temperatures. The moisture content of the gases can be measured with a General Electric dew-point apparatus. Connections are provided to three antennas on the roof so that, within the broadcast range, frequencies of the supersonic drivers may be calibrated against known broadcast frequencies.

The physical structure laboratory (room *6*) has 12 stations for experimental work on x-ray and electron diffraction, and a special room (*6a*) that serves both as a shop for the construction

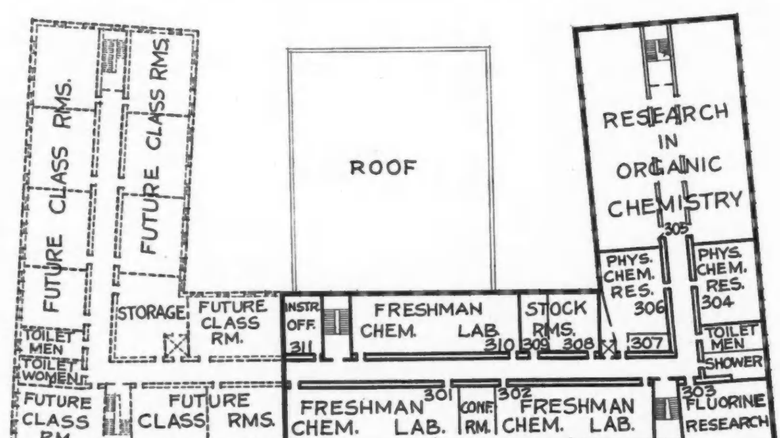


FIG. 5. Third floor plan.

of new equipment and as a room for the preparation of specimens for x-ray investigations. The "shop" portion is equipped with an 11-in. "toolroom" grade lathe, a drill press, a grinder, a belt sander, machinist's and carpenter's tables, and the customary tools. The rest of the room contains a glass-blowing table, a chemical bench with a hood, a hydraulic press for compacting specimens of metal powder up to pressures of 15 ton/in.^{2}, a swaging machine, with the customary furnace, for getting metal specimens in the form of rods, dies for drawing the rods into wires, and rolls for changing rods into ribbons. A table contains a high temperature furnace operating in a hydrogen atmosphere and a platinum furnace for heating oxides in air. In an alcove are two motor-generator sets which are intended to furnish constant voltage at 60 cycle/sec for x-ray work. By means of an autotransformer scheme, it is possible to get any desired voltage up to 120 v by 1-v steps at any one of the 12 experimental stations. A triple still with a 5-gal storage tank furnishes pure water for use in making specimens for diffraction work. An automatic hydrogen generator and purifier, piped to each of the experimental stations and to the "shop" furnaces, completes the list of general facilities of the x-ray laboratory. Each of the 12 stations has a 42-kv (max) transformer and kenotron housed in a wire cage, a rather complete switchboard wired for both a.c. and d.c., and hydrogen, gas, cold water, 15-lb/in.^{2} air, 80-lb/in.^{2} air, and sewer. Specialized x-ray equipment in this laboratory includes a thermostated spectrometer for temperatures up to 960°C, a spectrometer for simultaneously measuring the intensities of two diffraction lines, a spectrometer for measuring diffraction patterns of thermostated liquids, scanners for use in determining preferred orientations of mechanically worked metals, a McLachlan pole-figure machine, a standard General Electric diffraction outfit with accessories, a semiautomatic diffraction apparatus, and apparatus for filling and studying Geiger-Müller quantum counters. Accessory apparatus includes a large Littrow quartz spectrograph and automatic microphotometer for studying the purity of specimens. Still other equipment in the laboratory are an electron diffraction apparatus and an apparatus for studying scattering of beams of neutral molecules by gases. The laboratory has its own darkrooms.

Two small rooms (*13*, *14*), which represent spaces unavoidably set apart by a stairway, are equipped merely with benches, gas, air, water, sink, a.c. and d.c. and are for research that requires facilities which can be moved easily into the rooms.

The foregoing lists of facilities made available in special laboratories are worthy of attention not only for the items which they contain but also for the items which they do not contain. Each grouping represents a combination that has been found by some one or more men in the physics department to be desirable in connection with research along the lines of their natural long-time interest and therefore represents facilities for types of work which they may be expected to do especially well. These facilities in turn have attracted new men from time to time whose favorite topics of research require much the same grouping of special facilities. As their work branches out it is highly probable that still additional combinations of facilities may have to be provided on the third floor after the chemists move out. There has been no attempt to provide directly for newly fashionable topics of research, no matter how valuable, whose chief popular appeal depends upon their newness. This is in accord with the policy of the head of the physics department that the departmental work is not to be done on the basis of competition with other physics departments but rather that the department should emphasize the sort of work which it can do best.[4]

[4] The following information, as well as the data appearing in Tables I and II, was kindly furnished by the college Department of Grounds and Buildings:
Architects (associated): Chas. Z. Klauder; Hunter and Caldwell.
General contractor, McCloskey and Company.
Heating and ventilating contractor, Daniel J. Keating.
Electrical contractor, H. B. Frazier Company.
Plumbing contractor, Herre Brothers.
Fixed equipment contractor, E. H. Sheldon and Company.
Housing Committee, School of Chemistry and Physics: G. C. Chandlee, D. C. Duncan, H. L. Yeagley; W. P. Davey, *Chairman*.
Construction begun, June, 1938; ended, September, 1940.

Virtual Objects in Thin Lenses and Mirrors

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University of Cincinnati, Cincinnati, Ohio

SEVENTEEN recently published textbooks on general college physics were examined with reference to their treatment of virtual objects in mirrors and thin lenses. Virtual objects were not mentioned in seven books; in ten books they were discussed very briefly. The discussion was usually limited to a single example, solved analytically. The rules for ray constructions with virtual objects were not given in any of the 17 books. With one exception, virtual objects were not cited as the explanation of certain optical devices in which they appear. In the one exception, the author remarked that a virtual object exists in the Galilean telescope. The virtual object concept is mentioned, but not discussed, in the "Report of the A.A.P.T. Committee on the Teaching of Geometrical Optics."[1]

The analytical and graphical solutions of a general (thin) lens train problem require the virtual object concept, together with the rules for its use. Since almost all optical instruments involve lens trains, it is clear that a complete understanding of certain optical instruments necessitates a knowledge of virtual objects. Sometimes an attempt is made to dispense with the virtual object concept by the use of a single lens, equivalent to two lenses separated by a finite distance. This is not wholly satisfactory, owing to a well-known theorem:

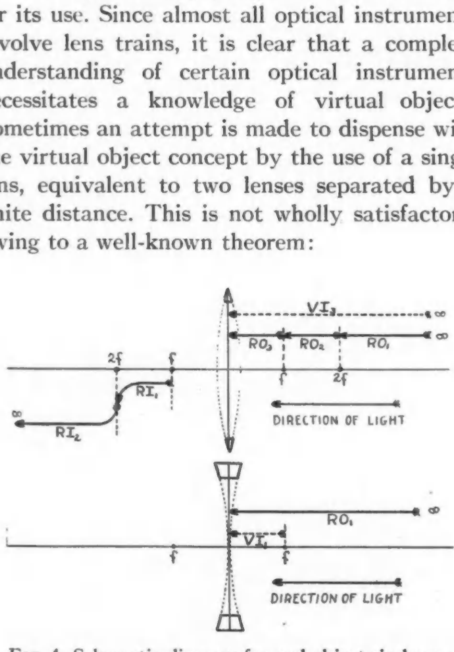

FIG. 1. Schematic diagram for real objects in lenses.

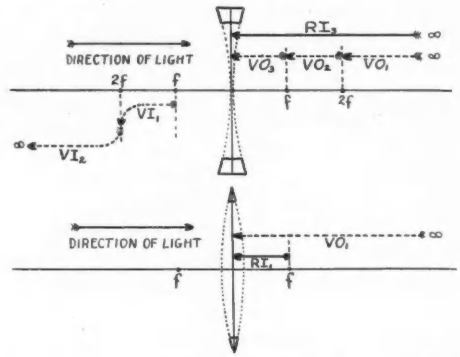

FIG. 2. Schematic diagram for virtual objects in lenses.

When two lenses, arranged so as to have a common axis, are separated by a distance too great to be neglected, it is impossible to find a single thin lens which, when placed in any fixed position, shall produce an image of the same size, and in the same position, as that produced by the combination. But a single thin lens can be found, which, when placed in a suitable fixed point, produces an image of the same size, but not generally in the same position, as that produced by the combination. This lens is

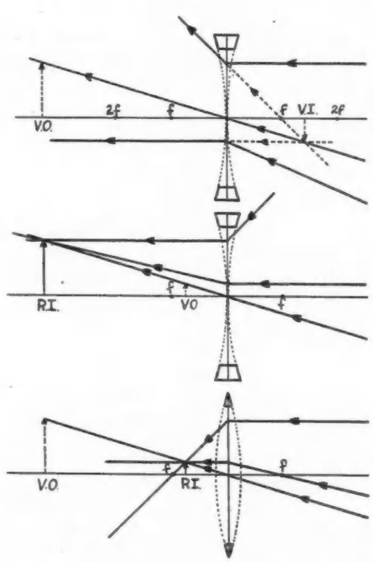

FIG. 3. Several ray constructions with virtual objects.

[1] Am. J. Phys. (Am. Phys. T.) 6, 78 (1938).

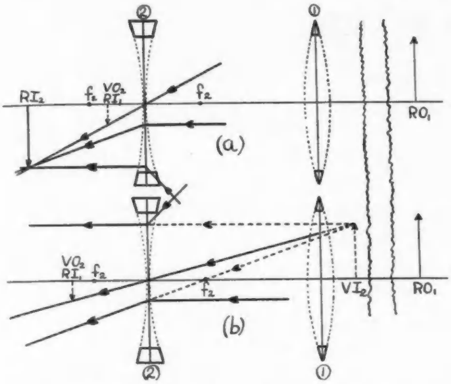

FIG. 4. Virtual object in (*a*) the tele-objective, (*b*) the Galilean telescope.

said to be equivalent (in the restricted sense defined above) to the combination.[2]

The use of the equivalent lens will, in general, lead to erroneous results, except when the lenses are in contact, for which case the error is small.

Since the theory of the virtual object is very simple and well known, it is presumed that the authors of general college physics textbooks do not consider the subject sufficiently important to warrant the space required for a full explanation; however, owing to the similarity of the behavior of real and virtual objects, the latter are easily understood and remembered, if presented properly. It is the purpose of this article to show how the behavior of virtual objects can be presented clearly and concisely.

A qualitative, schematic diagram may be used to show the behavior of the images formed by real objects for the two types of lenses (Fig. 1). A solid line for the range of the object (or image) distance indicates that the object (or image) is real; a dotted range line indicates that it is virtual. Corresponding range lines on opposite sides of the principal axis—for example, RO_2 and RI_2—indicate that the image is inverted; on the same side, that it is erect. If the image line is closer to the axis than the corresponding object line, the image is diminished; if farther from the axis, magnified. This pattern is easily memorized.

At the beginning of the study of lens (or mirror) trains, a complete list of the various things that can act as objects for a lens (or mirror) may be given:

(1) A real object may act only as a real object.

(2) A real image may act as a real object. The lens (or mirror) for which the real image is thus acting must be placed beyond the real image in the direction in which light is progressing.

(3) A virtual image may act as a real object. The lens (or mirror) for which the virtual image is thus acting must be placed beyond the first lens in the direction in which light is progressing.

(4) A real image may act as a virtual object. The lens (or mirror) for which the real image is acting as a virtual object must be placed between the real image and the lens (or mirror) producing it. The rays, which unmodified would have formed the real image, are now modified by the interposed lens (or mirror), and thus form an image elsewhere. The former real image is now called a *virtual object*. The same ray-construction rules are used as for real objects, except that the incident rays are drawn *toward* the virtual object

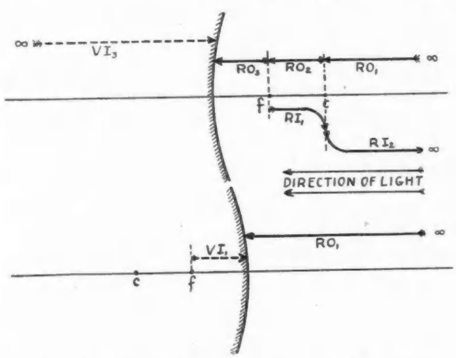

FIG. 5. Schematic diagram for real objects in spherical mirrors.

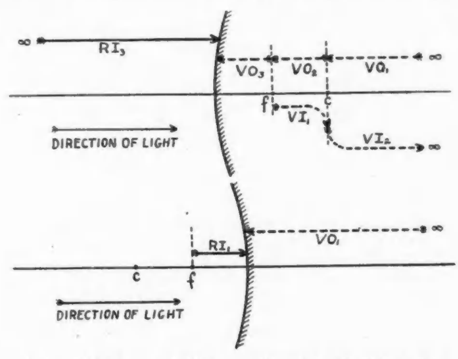

FIG. 6. Schematic diagram for virtual objects in spherical mirrors.

[2] E. Edser, *Light for students* (Macmillan, 1931), p. 74.

from the other side of the lens (or mirror). (See Fig. 3.) They are modified by the lens (or mirror) in the usual manner. The customary convention of signs applies; that is, the virtual object distance is considered negative in an analytical solution.

A qualitative, schematic diagram may be used to show the behavior of virtual objects in both

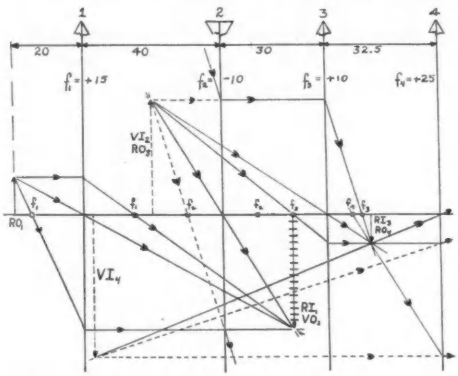

FIG. 7. A thin lens train problem solved graphically.

kinds of lenses (Fig. 2). The pattern is the same as that for real objects, except that the lenses are interchanged: real things in one diagram are replaced by virtual things in the other, and conversely; and the direction of the progression of light is reversed. Figure 3 shows several ray constructions with virtual objects in lenses. Figure 4 shows two optical devices in which virtual objects appear. Ray constructions are shown only for the virtual object and its image. Similar diagrams for the Huygen's eyepiece and the positive correction for hypermetropia can easily be made. Figures 5 and 6 show the schematic diagrams for real and virtual objects in spherical mirrors. Figure 7 shows a lens train problem of the type given to physics students at the University of Cincinnati as home work. In it will be found a real object, a real image acting as a real object, a virtual image acting as a real object, and a real image acting as a virtual object. The students are asked to lay out the lens train to scale; to draw complete 3-ray constructions, locating the final image; to measure the total magnification of the lens train; and to solve the problem analytically, including the location of the final image and the determination of the total magnification.

It is believed that a beginner would understand the principles of these devices and general lens trains much more clearly if they were explained with the use of virtual objects.

A Tube for the Franck-Hertz Experiment

ROBERT HOFSTADTER
Randal Morgan Laboratory of Physics, University of Pennsylvania, Philadelphia, Pennsylvania[1]

A HIGHLY informative exercise for a junior laboratory can be provided by the Franck-Hertz experiment for demonstrating the discrete energy levels of atoms. The simplest method for carrying out the experiment would seem to be to use a commercial vacuum tube or thyratron containing mercury, such as the FG-17 or FG-57.[2] Such tubes were tried by the author in the conventional Franck-Hertz circuit but did not appear to give more than one clear maximum in the curve showing the plate current as a function of the electron accelerating voltage.[3] This maximum, or peak, corresponded to the first excitation potential of mercury and to a single collision of electrons with mercury atoms. Additional peaks corresponding to second, third, . . . collisions never were evident. It was thought that poor geometry of the tube elements smoothed out the peaks; and, accordingly, tubes with better geometry—approximate cylindrical symmetry—such as 6C5, 6F6, WE262B and 42 were tried. These and the WE101F were opened in

[1] Now at the College of the City of New York, New York, N. Y.

[2] The FG-27 as suggested by Harnwell and Livingood, *Experimental atomic physics*, pp. 314–319, was not used because this tube was not readily available. However, other workers have informed the author that the present model of the FG-27 will not serve for an experiment of the Franck-Hertz type.

[3] The author has the kind permission of the directors of the Advanced Laboratory at Brooklyn College to mention that the FG-67 has been found to furnish two or three maximums under conditions of constant temperature in the neighborhood of 138°C.

air and a few small droplets of mercury were inserted. The tubes were then sealed off under vacuum. Among these the 6C5 gave three peaks, while the others proved much less satisfactory, often not showing more than a single peak. However, in the 6C5, the heater current necessary to maintain sufficient electron emission rose with the time until the heater burned out. Apparently mercury vapor or some other vapor or gas was poisoning the cathode, so that an individual 6C5 would not last more than a few hours. Various preliminary treatments of the cathode did not produce better results, although continuous pumping perhaps would have helped.

In view of these difficulties, it was decided finally that a homemade tube having good geometry and equipped with a durable, interchangeable cathode should be constructed. Since the original Franck-Hertz model had the necessary virtue of "working," a tube was constructed almost exactly to original dimensions.[4] A diagram showing dimensions is given in Fig. 1. Instead of the original platinum filament, a thoriated tungsten filament was used. The filament was prepared by spot welding a short length of approximately 11-mil thoriated tungsten wire to nickel leads. About 5 or 6 amp, a.c., through the filament circuit will produce sufficient electron emission. The presses shown in Fig. 1 were constructed by the local glass blower. This tube gave immediate and good results when operated in a 20° or 30° range around 110°C.

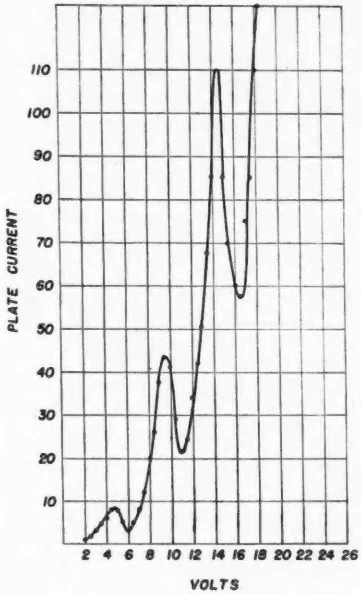

FIG. 2. Curve obtained with the tube.

The temperature did not seem to be very critical. A sample curve plotted from data taken with this tube is given in Fig. 2. The order of magnitude of the electron current was generally 10^{-9} to 10^{-7} amp, depending on the temperature inside the tube. In some runs peaks corresponding to accelerating voltages as high as 30 v were obtained. Satisfactory agreement with the known excitation potential of mercury—4.86 v—was obtained. Because of the presence of a thoriated tungsten filament and nickel electrodes, a correction for contact potential difference must be made in order to obtain the excitation potential from the position of any single peak. As is well known, the difference between the positions of neighboring peaks gives the excitation potential immediately. An internal accelerating grid spaced close to the filament was tried. In this case about 0.5 v was applied between the grids, making the electrons practically "coast" between them. This scheme did not have any advantages.

It is unfortunate that, owing to the pressing needs of the laboratory, no attempt was made to close the stopcock shown in Fig. 1 for the

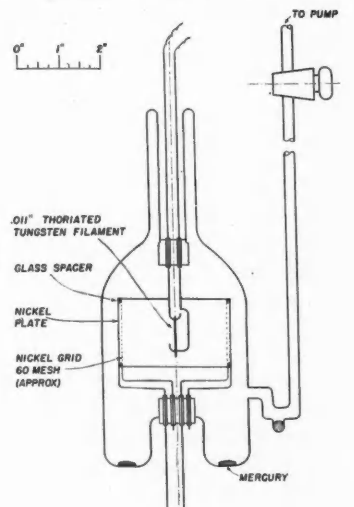

FIG. 1. Franck-Hertz tube.

[4] J. Franck and G. Hertz, Ber. d. Deut. Physik. Gesell 16, 457 (1914).

duration of several runs to see whether the tube, once outgassed, would continue to operate successfully thereafter. Such operation seems quite possible. It might also be worth while to substitute an oxide-coated sleeve cathode and heater for the filament, since electrical conditions in the tube would thereby probably be made more symmetrical.

A measurement of ionization potential may be made with this tube at lower temperatures than that mentioned here.

The author wishes to thank Professor G. P. Harnwell and Dr. D. S. Bayley for valuable advice. He is also grateful to Mr. J. Graham for his kindness in performing the necessary glass blowing.

A Remarkable Isochronous Pendulum

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University of Washington, Seattle, Washington

The period of a pendulum depends upon its construction, and, in general, any alteration in construction is accompanied by a change in period. As a striking exception to this generality, consider a $\perp$-shaped pendulum, whose bob is a straight, thin, uniformly heavy rod of length 6 units, rigidly attached at its midpoint to a perpendicular massless rigid supporting stem of length 1 unit, and which is free to oscillate in its own plane. The period of oscillation,[1] which is easily shown to be $4\pi g^{-\frac{1}{2}}$, is unchanged if the length of the stem is increased to 3 units. The period is said to be isochronous with respect to the given alteration of the pendulum.

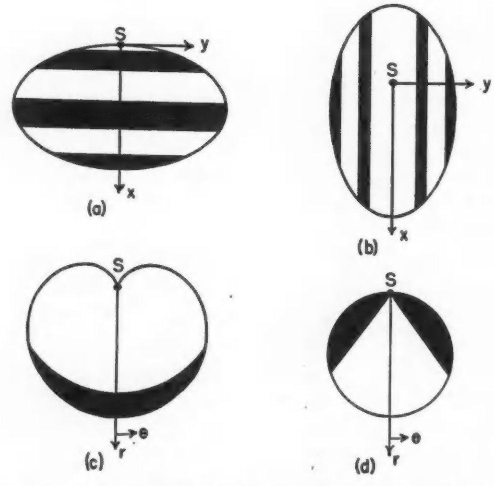

Fig. 1. Four cases in which a pendulum supported at S is unchanged in period by the removal of portions such as those indicated in black.

[1] We shall restrict the discussion to small amplitude.

This special case of isochronism suggests other more general cases, of which some are indicated below. We shall discuss several pendulums, each of which is plane and free to oscillate in its own xy-plane about a fixed point. Generalizations of these cases are readily conceived.

Consider a lamina of given shape as specified by a boundary curve $y_1(x)$ and surface density $\sigma(x, y)$ which need not be uniform, supported so as to be free to oscillate in its own plane as a pendulum. In general, of course, the period of the oscillation is changed by any alteration in the shape or the surface density; but there are certain alterations that leave the oscillations isochronous. For a given case of isochronism there is a relationship between the density distribution, boundary curve and manner of alteration. If two of these functions are specified, the third may be found, although not always uniquely. In what follows, the density distribution and manner of alteration will be taken as known, and the boundary curve will be calculated. The restrictions will be imposed throughout that the lamina has bilateral symmetry—that is, the boundary curve is symmetrical about the x-axis, as in Fig. 1—that $\sigma(x, y)=\sigma(x, -y)$, and that the origin of coordinates is at the point of support (except in Sec. **5** below).

1. Let us find the shape of the pendulum that is isochronous with respect to truncation along a line perpendicular to its line of symmetry. Take the point of support at the origin of axes (x, y) fixed in the lamina, with the x-axis passing through the center of mass. It is required that the pendulum be isochronous with respect to the alteration of cutting off the part below any

arbitrary point $x=x_1$. The angular frequency $\omega[=2\pi/\text{period}]$ is given by

$$g\omega^{-2}=I/mx_c, \tag{1}$$

where

$$I=2\int_0^{x_1}\int_0^{y_1(x)}(x^2+y^2)\sigma(x, y)dydx$$

is the moment of inertia of the pendulum as altered, about the normal through the origin, and

$$x_c=(2/m)\int_0^{x_1}\int_0^{y_1(x)}x\sigma(x, y)dydx$$

gives the position of the center of mass. For isochronism it is required that $d(g\omega^{-2})/dx_1=0$, which reduces to

$$g\omega^{-2}\int_0^{y_1(x_1)}x_1\sigma(x_1, y)dy = \int_0^{y_1(x_1)}(x_1^2+y^2)\sigma(x_1, y)dy. \tag{2}$$

This equation shows how to calculate the required boundary curve $y_1(x)$.

If, for instance, the body is a thin rigid uniform wire, we have $\sigma(x, y)=\text{const.}$ on the bounding curve and $\sigma(x, y)=0$ elsewhere. For this case we find from Eq. (2) that $g\omega^{-2}x_1-x_1^2-y_1^2=0$, showing that the character of σ and of the alteration in question require the body to be a circular loop of diameter $g\omega^{-2}$, hanging on a hook. The oscillation of this pendulum is isochronous with respect to any alteration that leaves equal arcs on each side of the point of support.

If, alternatively, $\sigma(x, y)=f(x)$ is an arbitrary function of x alone, then Eq. (2) leads to

$$3g\omega^{-2}x_1-3x_1^2-y_1^2=0 \tag{3}$$

for the bounding curve. Equation (3) represents an elliptical lamina of major diameter $g\omega^{-2}\sqrt{3}$, hung from one end of its minor diameter $g\omega^{-2}$ as in Fig. 1(a). The portion above any horizontal line has the same period, as indeed has any black part or any white part; this pendulum is in fact isochronous with respect to any change in $f(x)$, the alteration of cutting off at $x=x_1$ being the special case in which $f(x)$ is made to vanish for $x>x_1$. The pendulum mentioned in the opening paragraph is also a special case, since Eq. (3) is satisfied by the coordinates of the ends of the rod in either of its positions.

2. Let us find the shape of the pendulum that is isochronous with respect to cutting simultaneously along any two lines parallel to the line of symmetry and situated equally to the right and left of it, as in Fig. 1(b). Regarding the boundary of the lamina as $x_1(y)$ and cutting off the sides of the lamina at $y=\pm y_1$, we have, by differentiating Eq. (1) with respect to y_1,

$$g\omega^{-2}\int_{x_0}^{x_1(y)}x\sigma(x, y_1)dx=\int_{x_0}^{x_1(y)}(x^2+y_1^2)\sigma(x, y_1)dx$$

as the condition for isochronism. If $\sigma(x, y)=f(y)=f(-y)$ is any symmetrical function of y, this condition becomes

$$\tfrac{1}{2}g\omega^{-2}(x+x_0)=\tfrac{1}{3}(x^2+xx_0+x_0^2)+y_1^2.$$

This equation represents an ellipse of the same shape as that described by Eq. (3), supported at an arbitrary point on (or on a prolongation of) its major diameter, as in Fig. 1(b). Each of these laminas has lines of constant surface density σ parallel to the major diameter.

3. The oscillation of the heart-shaped uniformly dense lamina $r=g\omega^{-2}\theta^{-1}\sin\theta$ about its origin is isochronous with respect to the elimination of a portion by means of a cut along any circle $r=\text{const.}$, as in Fig. 1(c). It is also isochronous if $\sigma=\sigma(r)$ is any function of r.

4. The oscillation of a disk $r=(4/3)\ g\omega^{-2}\cos\theta$

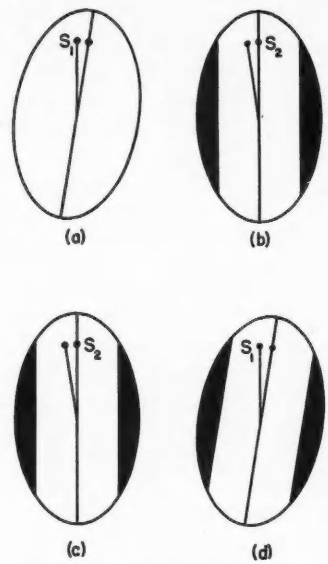

FIG. 2. The pendulum at (a), supported at S_1, is isochronous with respect to the alteration shown at (d).

about a point on its circumference is isochronous with respect to the removal of the two lunes obtained by cutting along any two equal chords drawn from the point of suspension, as in Fig. 1(d). It is also isochronous if $\sigma=f(\theta)=f(-\theta)$ is any symmetrical function of θ.

5. The lamina discussed in Sec. **2** has an additional property; if supported at any point S_1 inside or outside its boundary, it oscillates isochronously with respect to alterations of the type defined in Sec. **2**, and indeed the period of these oscillations is independent of the density function $f(y)$. This is evident from Fig. 2, in which the respective values of ω are ω_a, ω_b, ω_c and ω_d. We have $\omega_b=\omega_a$ since, by construction, the distances from the center of mass to S_1 and S_2 are equal and the moments of inertia about S_1 and S_2 are equal; and $\omega_c=\omega_b$ in virtue of Sec. **2**; and $\omega_d=\omega_c$ for the same reason that $\omega_b=\omega_a$.

Of the several pendulums discussed, the one most worthy of the title role in this paper is the pendulum described in Secs. **2** and **5**. It is an elliptical lamina whose principal diameters are in the ratio $\sqrt{3}:1$, and whose density is a symmetrical function of the distance from its major diameter. It is pictured in Figs. 1(b) and 2. A model has been constructed that can be supported at any one of several points, altered in shape by removing sections parallel to the major diameter, and altered in density by loading it with rods which can be fastened parallel to the major diameter and which end at the edge of the lamina. No matter at which point this model is supported, the oscillations are not significantly changed in period by any such alteration that is symmetrical with respect to the major diameter; and if, in particular, the model is supported at one end of the minor diameter, its oscillations are isochronous with respect to any such alteration, whether symmetrical or not.

Some Demonstration Experiments in Light

JOHN ZELENY
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THESE simple demonstration experiments in light are not found in books on the subject and are here briefly described in the hope that they may be of interest to some who are not now familiar with them. A number of the experiments I first saw done about 45 years ago by Sir G. G. Stokes who was then 80 years old. In his lectures he used the candle and the sun as his sole sources of white light.

REVERSAL OF THE SODIUM LINES

1. An unusual experiment for showing that sodium vapor strongly absorbs light of the same frequency as it emits when excited consists simply in placing an ordinary Bunsen burner sodium flame in front of a large smooth block of white chalk. The edges of the flame, where the cooled less luminous vapor absorbs strongly the more intense sodium light reflected by the chalk, appear quite dark against the light background. This is best seen near the base of the flame where the edges remain stationary. Lacking a block of chalk or some other material having a very high reflectivity, one may hold a stick of school crayon, which has been ground flat, in a horizontal position behind the sodium flame; but the experiment is now less impressive.

2. In some textbooks the diagrams of the apparatus for the reversal of the sodium line show the spoon that holds the metallic sodium placed in front of the slit. With this arrangement an annoying glare from the sodium light is unavoidably spread by the projection lens over the spectrum on the screen. This difficulty is avoided by placing the sodium light behind the slit, since any light passing outside the slit can now be screened off.

INTERFERENCE OF LIGHT FROM THICK PLATES

1. A spectrum of white light reflected from a film thin enough to show colors exhibits at most only a few broad absorption bands. The more numerous interference bands that are found in the spectrum of light reflected from a film which is too thick to show colors may be simply shown as follows. A thin sheet of mica is bent around and attached to the surface of an opaque cylinder, 3 to 4 mm in diameter, which is supported in a

vertical position a short distance from a candle flame or an incandescent filament that serves as the source of white light. The narrow image of the light source in the cylindrical film acts as a slit for the spectral analysis. The reflected light after dispersion by a prism or by a diffraction grating may be viewed directly by the eye or preferably through a telescope. The sheet of mica employed should not have a thickness of much over ten wave-lengths of light. Some patience is required to peel off a sheet so thin, but a very small piece suffices.

2. The dark bands which also appear in the spectrum of white light transmitted by a mica film can be projected on a screen by placing the piece of mica directly upon the slit of the projection apparatus. Owing to the small portion of the incident light that is reflected at normal incidence, the bands are rather faint. Doubtless they could be enhanced by coating the mica on both sides with semi-transparent metallic films.

WHEWELL'S COLORED BANDS

1. The wide interference fringes known as Whewell's bands are seen with the unaided eye by observing the image of a candle in an ordinary glass plane mirror placed about 3 or 4 m away from the candle. The surface of the mirror, which should be about 20×35 cm, must be covered with small particles for scattering the incident light. Suitable particles are best deposited on the mirror by first covering it with milk diluted with three or four parts of water, then allowing the solution to drain off, and finally letting the remainder dry onto the surface. Thus prepared, the mirror may be used over and over again for many years. However, a mirror dusted with chalk or flour answers the purpose equally well. The image of the candle is observed with the eye placed directly behind and some distance beyond the candle; and the very distinct colored fringes, which are from 1 to 3 cm wide, appear on either side of the candle, their position changing, however, with motion of the observer's head. The fringes are produced by the interference of light that reaches the eye by two nearly equal paths: in the one path the light, after being scattered inward by particles on the front surface of the mirror and reflected from the back, comes out between the particles; in the other path the light enters the mirror between the particles, is reflected from the back and reaches the eye after being scattered forward by the particles.

Whewell's bands are closely related to the bands produced under like conditions by a concave mirror, and these were first described by Newton. In this case the bands are focused in space and are concentric with the candle when it is held at the center of curvature of the mirror. If a screen with a small hole in it is supported with the hole at the center of curvature of the mirror and a beam of light is sent through the hole toward the mirror, the circular fringes are formed on the screen itself.

Both types of the aforementioned fringes are described in Preston's *The theory of light*, and a complete theory of them is given by Stokes.[1]

EXPERIMENTS WITH INFRA-RED RAYS

The fact that infra-red rays when falling on a fluorescing screen have a quenching effect upon the light may be used advantageously for the following two experiments.

1. To show that infra-red rays are present in a prism spectrum of the light from an arc lamp.—The slit used in projecting the spectrum should be rather wide and its length adjusted so that the spectrum on the screen has a width of about 5 cm. A fluorescent screen (calcium tungstate) about 30 cm square is first exposed for a few seconds to the direct light of the arc at close range and then is placed just outside of the red end of the spectrum on the screen. After an exposure of about 10 sec to the infra-red rays the screen is removed and a dark band having the same width as the spectrum is now found to extend a part of the way across the luminous screen, showing that invisible rays were present beyond the red end of the spectrum. This experiment succeeds even when glass lenses and prisms are used for projecting the spectrum.

2. To show the transparency of hard rubber for infra-red rays.—A sheet of hard rubber 0.2 mm thick is sufficiently transparent to the extreme red rays of the spectrum so that bright objects can be recognized through it. Sheets of hard rubber nearly a millimeter thick, such as are used in photographic plate holders, transmit the infra-red rays quite readily. To demonstrate this,

[1] G. G. Stokes, Camb. Phil. Trans. **9**, 147 (1851).

a fluorescent screen such as the one previously described is first exposed to direct arc light and, while shining brilliantly, is covered with the sheet of hard rubber being tested. A hand with fingers spread out is now placed on top of the hard rubber, and the combination is again exposed for a few seconds to direct arc light at close range. On removal of the hand and the hard rubber sheet from the screen, the portions of the screen that had been protected from the rays by the hand are found to be shining much brighter than the rest of the screen to which the rays had penetrated through the hard rubber.

STOKES' LAW FOR FLUORESCENT LIGHT

Stokes' law states that fluorescent light has a lower frequency than the light which excited it.[2] This may be illustrated by focusing the light from an arc lamp upon a cube of uranium glass after it has passed through a filter that transmits only the extreme violet end of the spectrum. The bright greenish light coming from the fluorescing cube can be completely extinguished by interposing in the path of the incident light a sheet of amber-colored glass which transmits light only from the low frequency end of the spectrum. However, when the amber-colored glass is now placed between the fluorescing cube and the audience, the light coming from the cube is found to be readily transmitted.

DEPENDENCE OF REGULAR REFLECTION ON LIGHT FREQUENCY

For regular reflection of waves a reflecting surface must be smooth enough so that the paths of the waves reflected from the tops of the ridges on the surface shall differ from those reflected from the valleys between by not more than a small part of the wave-length λ; that is, $2h \cos \varphi$ must be small relative to λ, h being the height of the hills and φ the angle of incidence. For a given surface this condition is the more easily satisfied the larger is φ and the larger is λ. As is well known, surfaces that do not show regular reflection of light at normal incidence may do so at grazing incidence. The dependence of the limiting angle for regular reflection upon the wave-length of the light used may be shown in the following way. The image of a candle or of the filament of a lamp is observed at grazing incidence in a long piece—5×20 cm—of finely ground glass or in a surface coated with an even opaque layer of soot deposited *in situ*. When the reflecting surface is now turned slowly so as to decrease the angle of incidence φ, the image seen clearly at first finally disappears rather suddenly. However, before doing so its color has changed to red, showing that regular reflection continues to smaller values of φ for the longer waves, in accordance with the condition previously stated.

[2] This law is not valid for all portions of the band of fluorescent light.

UNEVENNESS OF A SURFACE MAGNIFIED BY REFLECTED LIGHT

Deviations from planeness in a piece of ordinary window glass show up as hills and valleys of astonishing magnitude when light coming directly from a small arc lamp is reflected from the glass at nearly grazing incidence onto a screen. The experiment can be repeated to advantage with a piece of plate glass to bring out the contrast between the two reflected patterns.

THE PHENOMENON OF THE PHANTOM PALINGS

This well-known effect is observed best by looking from some distance at a light background through identical picket fences which are on two parallel sides of a plot of ground. The large, alternately light and dark bands which are seen constitute the phantom palings. The effect may be easily shown in a classroom by using a small arc lamp, without lenses, as a source of light and throwing upon the screen the overlapping shadows of two similar coarse combs, with teeth 2 cm or more long, which are placed at somewhat different distances from the light. The explanation may be left as an exercise for the students. Two identical wire gauzes may also be used. The shadowy "water lines" observed on looking through the folds of a lace window curtain are obviously effects of the same nature.

America's first need is leaders who can think accurately and with confidence.
—W. E. Weld.

NOTES AND DISCUSSION

Does a Baseball Curve?

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THE recent discussion provoked by the magazine *Life*[1] as to whether there is any such thing as a baseball curve prompted the following experiment.

Figure 1 is a photograph of the physical set-up. A series of screens was placed along a line joining the pitcher's mound and home plate. The screens consisted of nets of fine, black cotton thread strung 1 in. apart horizontally and vertically. The momentary position of a ball passing through a net was indicated by torn or displaced threads. The screen nearest the pitcher's mound was 6 ft wide and 5 ft high. The other four screens were each 4 ft square. The locations of the screens along the line between home plate and the pitcher's box are given at the top of Fig. 2. Vertical and horizontal datum lines were accurately alined and drawn on all the screens with the aid of a surveyor's transit. The tall structure seen directly behind home plate in Fig. 1 is a support for a ballistic pendulum which was used to measure baseball speeds.

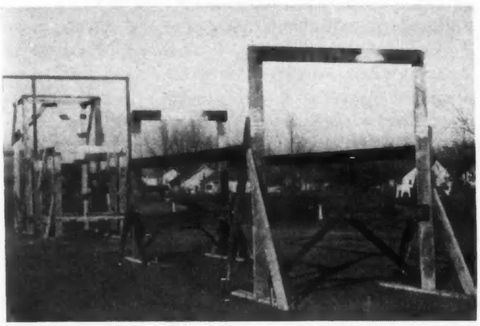

FIG. 1. Photograph of the set-up.

In the course of the experiment nine throws that passed through all the screens were measured. After every throw careful readings of the horizontal and the vertical displacements of the ball position from the datum lines on all the screens were taken and the torn threads were repaired. The uncertainty in determining the point of passage of the ball was never more than 1 in. The pitchers were three students on the school baseball team and one professional ball player.

Of the nine throws one was an intentional straight ball, six were right-handed outdrops, and two were left-handed outdrops. The outdrop seems to be the easiest "curve" for most pitchers to throw. Both right-handed and left-handed outdrops were thrown on the same day under similar atmospheric conditions.

Figure 2 shows the horizontal projections, drawn to scale, of the straight ball, one left-handed outdrop and one right-handed outdrop. For the latter two the projections were drawn twice, once with a doubled scale. These graphs reveal unmistakable curvatures. So do the horizontal projections of all the other six outdrops thrown. The deviations at home plate from straight-line travel vary for all the outdrops from 2.5 to 6.5 in. The maximum error in these figures is estimated to be not more than 1 in. It should be noted that there were no throws called "curves" by the pitchers which were not found to be

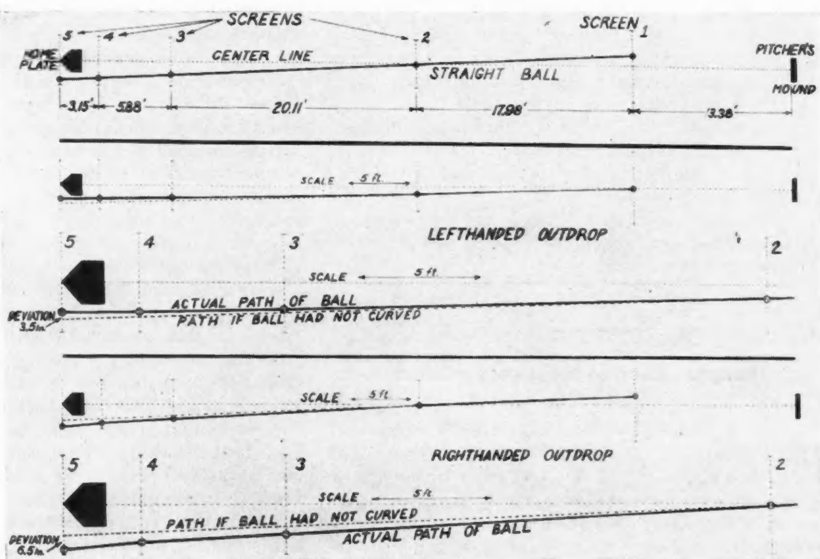

FIG. 2. Horizontal projections of baseball flights.

"curves" when measured. In all cases the curvature of the horizontal projections is observed to be negligible up to the last 25 ft of travel.

The vertical projections of the throws were also plotted. From simple calculations it was found that the balls dropped more sharply than would be the case for free fall alone. However, from the data available it was not possible to analyze the vertical drops into the three possible components—the gravitational fall, the air resistance effect and the drop due to spin.

The horizontal speed that pitchers can impart to a ball ranges from about 90 to perhaps 130 ft/sec. The distance the ball travels from the pitcher's extended hand to the batter is approximately 50 ft. The time of travel is therefore close to 0.5 sec, with 0.4 sec as a minimum. In its last 25 ft of travel a good outdrop accordingly deviates, say, 6 in. from its horizontal direction of throw in 0.25 sec. This amounts to an average horizontal tangential speed of 2 ft/sec. This motion across the line of sight has been seen by many competent observers; it must be responsible for the optical impression of the so-called "break" of the ball. The physiological readjustments of the eye involved in watching an approaching ball are obviously different for the tangential and the radial components of velocity. It is likely that the tangential component of 2 ft/sec is more effectively observed than the radial component of 100 ft/sec. This may possibly be sufficient to explain the strong sensation of a "break" reported by many reputable witnesses.

It is interesting to note that, with a horizontal speed of 130 ft/sec, a pitcher need give a ball only enough vertical velocity to make it rise 7.5 in. in 0.2 sec in order that the ball shall arrive at the plate at the same horizontal level from which it started (neglecting air resistance). Now if the pitcher can impart enough spin to the ball to make it deviate 7.5 in. upward, the ball will travel practically in a horizontal plane. Conceivably the maximum speed and spin attainable by a Walter Johnson or a Bob Feller might even give the ball a slight "hop" or vertical rise in its flight toward home plate.

A study of the data and of the horizontal projections has led to the following conclusions: (1) Baseballs do "curve"; (2) the curvature of baseball flights is slight; but, being across the line of sight, it is probably sufficient to explain the impression of "curves" and even "breaks"; (3) many other peculiar effects reported about baseball curves are not explained.

[1] *Life*, Sept. 15, 1941, p. 83

Demonstration of the Doppler Effect

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PROFESSOR C. W. Heaps[1] contends that the old method of showing the Doppler effect by noting the beats heard when a sounding fork is moved back and forth in front of a reflecting wall, which I recently advocated as preferable to other methods used for showing the effect,[2] is in fact not unambiguous. He maintains "that no change in wave-length is necessary in order that beats be produced in this demonstration."

Briefly summarized, his argument is as follows. Suppose at the start that a source of sound of frequency n is held stationary at such a distance from a reflecting wall that the reflected wave train after passing the source is in phase with the direct system moving from the source to the observer. The two wave systems amplify each other continuously. If the stationary source be now moved in succession to new positions for which its distance from the wall is changed progressively by steps of a quarter of a wave-length at a time, the reflected train will alternately be either out of phase or in phase with the direct system for the whole distance between the source and the observer. As the source and the wall are both stationary, the waves in both systems have the same lengths and yet for these successive stationary positions of the source the observer hears continuously either a loud sound or a weak sound.

Professor Heaps then asserts that if the source of sound be now moved with a uniform speed through the points just described the observer will as before hear loud and weak sounds in succession at intervals of $\lambda/4V$ sec, λ being the wave-length of the sound and V the speed of the source; that is, $2nV/v$ beats will be heard per second, v being the speed of sound.

However, there is a fallacy inherent in thus passing from the effects observed when the sound source is moved by steps to the case of a source moving with a uniform speed. If two trains of waves of equal length be supposed moving in the same direction, the only way one train can be alternately in step and out of step with the other train is to have one train pass through the other as they move along. This implies that the two systems, having identical wave-lengths, have different speeds, which is evidently impossible. All pairs of overlapping points in the two wave trains move along together and the same phase relation necessarily exists everywhere continuously between the individual points of each pair. The moving sound source does not accelerate the whole wave system moving in one direction and retard that moving in the opposite direction. What the moving source does do is to make the waves in one set shorter and in the other set longer than they are normally when the source is at rest, and this, of course, is the Doppler effect. No other logical conclusion can follow from the premises that the number of waves sent out by the source in a given time in the two directions is the same and that these waves are spread out over a shorter distance in one case than in the other.

Professor Heaps mentions an experiment described by Koenig for demonstrating the Doppler effect in which two forks differing slightly in pitch are both sounded and the change in the frequency of the beats is noted as one of the forks is moved back and forth relative to the other. In a somewhat similar experiment due to Mayer[3] the stationary fork of the aforementioned pair is not sounded but is made to respond by resonance when the other, vibrating fork is moved relative to it at the proper speed.

In repeating the first of these experiments, I found it rather difficult to perceive with certainty the change in frequency of the beats, possibly because in moving the

one fork out to arm's length and back again the time taken for each motion is rather short. In the second of these experiments, the response of the resonating fork was found to be too feeble to be heard more than a few feet away. The difficulty here is to get just the right speed necessary to bring on resonance, so I resorted to the use of a changing speed in the hope that during such part of the time that the waves reached the stationary fork at the proper intervals it would respond sufficiently to be heard.

As the most satisfactory experiment for illustrating the Doppler effect to students, I, therefore, still recommend the one in which beats are produced by moving a fork back and forth in front of a wall. For best results, the fork used should have a high pitch (C^4) and it should be moved slowly. It should have wide prongs so as to produce a loud sound without the aid of a resonator. For some reason, forks on resonator boxes do not show the effect at all well.

An interesting modification of the experiment with the fork moving in front of a stationary wall is to hold the fork stationary and move the wall back and forth behind the fork. A thin wooden board of area 1 to 2 ft² suffices for the wall, and the beats produced are just as distinct as those heard when the fork is moved. Here, the waves coming directly from the stationary fork to the observer naturally have their normal lengths, while those reflected from the moving wall suffer the well-known alteration. The frequency of the beats produced may be found simply as follows. Suppose that the wall is approaching the fork and that at a given instant the head of one wave has just reached the wall at a position A. Its tail will then be at a position we shall call B, at a distance $vT_0[=\lambda_0]$ from the wall, v being the speed of sound and T_0 the period of the waves. The tail of the wave will reach the moving wall in a time t, during which time it will have gone a distance vt, while in the same time the wall will have moved to C, a distance Vt, where V is the speed of the wall. Hence

$$(v+V)t=vT_0. \quad (1)$$

During the time t, the head of the reflected wave will have gone to D, a distance vt from A, and its distance from B will then be Vt. The head of this wave will now be a distance

$$CD=vT_0-2Vt \quad (2)$$

from its tail, and hence this distance is the wave-length λ_1 of the reflected wave. Eliminating t between Eqs. (1) and (2) and finding the new frequency n_1 in terms of the fork frequency $n_0[=1/T_0]$

$$n_1=n_0(v+V)/(v-V). \quad (3)$$

Thus the number of beats heard per second by an observer beyond the stationary fork is,

$$n_1-n_0=2n_0V/(v-V). \quad (4)$$

The frequency of the beats in the experiment in which the fork is moved and the wall is stationary is $2vVn_0/(v^2-V^2)$. The two values are seen to be nearly equal when V is small compared with v.

REPLY TO PROFESSOR ZELENY

Professor Zeleny's criticism is definitely apropos. It is certainly true that a tuning fork can occupy successive positions in front of a reflecting wall and, for these positions, produce either maximums or minimums of sound, the wave-lengths of the direct and reflected sound being identical. However, it is also true, as Professor Zeleny points out, that in order for the continuous transition from maximum to minimum to occur the Doppler effect must be invoked.

Is there not room for a difference of opinion regarding the effectiveness of the experiment in demonstrating the Doppler principle? Demonstrations should be simple and direct, or if complex, should be completely and clearly explained. Many lecturers might not wish to take as much time as would be needed in explaining this demonstration clearly to a class of beginners. I have found that the few students who have never detected pitch changes caused by driving past a sound source are able and anxious to make the observation themselves in their own automobiles. They thus have the double advantage of choosing the simplest experiment and of participating in it.—C. W. Heaps.

[1] C. W. Heaps, Am. J. Phys. 9, 313 (1941).
[2] J. Zeleny, Am. J. Phys. 9, 173 (1941).
[3] A. M. Mayer, Pogg. Ann. 146, 110 (1872).

The Cooperative Committee on Science Teaching

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VARIOUS investigations by committees and individuals on phases of the teaching of the basic sciences in schools and colleges throughout the country have led to a recognition that many of the problems cannot be solved except by cooperative effort of all concerned. Consequently, several informal meetings of interested people have been initiated by K. Lark-Horovitz, of Purdue University.[1] These meetings have been attended by mathematicians, physicists, chemists, biologists and educationists. In April, 1941, the Cooperative Committee on Science Teaching was created by representatives of several societies. Robert J. Havighurst, of the University of Chicago, was elected chairman. The writer was named secretary.

The members of the committee and the organizations which they represent are as follows:

American Association of Physics Teachers—K. Lark-Horovitz, Purdue University; Glen W. Warner, Woodrow Wilson City College.
American Chemical Society—B. S. Hopkins, University of Illinois; Martin V. McGill, Lorain (Ohio) High School.
Mathematical Association of America—A. A. Bennett, Brown University; Raleigh Schorling, University of Michigan.
Union of Biological Societies—Oscar Riddle, Carnegie Institution of Washington; Walter F. Loehwing, Iowa State University.
National Association for Research in Science Teaching—G. P. Cahoon, Ohio State University; Robert J. Havighurst, University of Chicago.

This committee will have an advisory relation to its parent organizations. It will report to them regularly

through their representatives and will publish its recommendations in various journals with the aim of securing comment and criticism by members of the sponsoring organizations.

Two meetings have been held, one in April and one in November, 1941. Work is now in progress on the following four problems.

(1) *Licensing or certification of secondary school science teachers.*—This problem, with its associated problem of combinations of subjects to be taught by the beginning teacher in the small school, is generally recognized as a serious one. Most teachers begin their work in small secondary schools of 200 or fewer students, where one must teach three or four different subjects. Therefore, a college graduate with highly specialized training in a single science is at a disadvantage in securing a position and in his teaching if he is appointed. The committee hopes to formulate a policy upon which all the societies can agree and that suits the realities of the teaching situations. The committee wishes to make this study so thorough and the recommendations so practical that its report can be used by certification authorities as a basis for action.

(2) *College training of prospective science teachers.*—The committee recognizes the difficulty of preparing science teachers for such broad teaching assignments as are given to most new teachers. This problem will require careful study with the aim of planning a program that will afford the necessary breadth of science training, give adequate opportunity for specializing in one science, and provide for professional courses in education as well as a sufficient number of courses for general culture.

(3) *Exploratory studies of the school science curriculum through workshops and conferences.*—The committee hopes to stimulate the science departments of a number of colleges and universities to bring secondary school teachers to their campuses for cooperative work on educational problems. Out of such workshops and conferences would probably come plans for improved science courses. These activities would provide good in-service training for science teachers and would enable them to make their problems and their points of view evident to the college scientists.

(4) *State or local agencies needing the services of educational consultants on questions pertaining to science teaching.*—The committee offers its services as a consultant to state or local agencies working on problems pertaining to science teaching. Direct connection would thus be provided between such agencies and the societies represented on the committee. For example, the committee might become associated in a curriculum study in some state, cooperating with the state department of education and the college and school science teachers of that state. The results of such a project might also prove valuable to other states.

These four educational problems are of vital interest to all science teachers and are among those which it is believed no single organization can solve working alone.

[1] See "Report of the A. A. P. T. committee on the teaching of physics in secondary schools," Am. J. Phys. **10**, 60 (1942).

On the Certification of Science Teachers in Secondary Schools

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A committee for the promotion of science in secondary education for the State of Pennsylvania was called together for organization in September, 1941, by Professor A. G. Worthing, President of the American Association of Physics Teachers. The specific purpose of this committee is to obtain unified action by the various scientific societies of the state on matters pertaining to secondary school education in the sciences. The committee also hopes to correlate the activities in Pennsylvania with the work of a similar national committee[1] and also with the work of the national societies.[2]

The committee has held three meetings, at which many aspects of the problem were discussed. However, at this time the committee wishes to make recommendations only on the certification of teachers. The recommendations listed in Part I are specific, and it is hoped that the various societies will endorse them so that the committee can present them with the proper support to the Pennsylvania State Board of Education. The recommendations listed in Part II are more general in character; means for making them effective will have to be considered later, and their usefulness may depend upon the results obtained with those in Part I.

PART I

1. (*a*) An applicant may be certified to teach *biology* or *chemistry* or *mathematics* or *physics* only if he has completed a minimum of 18 semester hours in the particular one of these subjects for which he is to be certified.

(*b*) To be certified for *general science*, the applicant must have completed a minimum of 18 semester hours in *one* of the subjects listed in 1(*a*), and 8 semester hours in each of any *two* of the other subjects.

(*c*) Certification shall not be granted in these subjects [1(*a*) and 1(*b*)] by any other name that would permit the applicant to teach these subjects with less than the preparation specified. For example, certification shall not be given in *physical sciences* unless the applicant has 18 semester hours in physics and 18 semester hours in chemistry.[3]

2. The permanent college certificate shall require three years of successful teaching experience on the provisional college certificate and the satisfactory completion of 12 (instead of 6, as at present) semester hours of additional work of collegiate grade completed subsequent to the issue of the baccalaureate degree. Of this additional work, 3 semester hours must be professional and the remaining 9 (instead of 3) must be in the subject, or subjects (not merely related to the subjects, as at present), written on the face of the certificate.

3. The present code includes the following provision: "When the extension of an emergency certificate beyond the first year is requested, the district or county superintendent will furnish evidence of: (1) progress in the reorganization of the school program which will remove the necessity for the emergency certificate; or (2) the completion by the teacher of additional education in approved courses in the field covered by the emergency certificate. (A minimum of 6 semester hours each year is expected.)" The last word, "expected," shall be changed to "required."

PART II

1. (*a*) A National Science Council, democratically elected and administered, with a full-time paid secretary and adequate staff, should be established in connection with the National Education Association with headquarters in Washington, D. C. (Almost all other fields are so represented in the N.E.A.)

(*b*) There should be a State Science Committee or Council to recommend, and supervise, so far as that is possible, the certification of science teachers in the State of Pennsylvania.

2. Increments in salary, rather than being automatic, should be contingent upon the completion of further work in the field or fields for which the teacher is certified. The attainment of an advanced degree should *not* be the controlling factor irrespective of whether the work was in the fields of certification.

3. The establishment of certification requirements does not in itself provide teachers who can meet these requirements. Colleges and universities engaged in teacher training should examine their curriculums in the sciences as to their suitability for prospective teachers. Adequate courses should be available both for the prospective teacher and for the teacher who wishes to extend his education in science. At present the teacher who wishes to improve his status finds too little encouragement to pursue courses in his major field.

4. Some form of recognition should be given to well prepared and successful teachers so as to focus public attention and the attention of school boards on good preparation.

The membership of the committee and the societies represented are as follows: E. L. Haenisch, Pennsylvania Chemical Society; John C. Johnson, Pennsylvania Academy of Science; C. O. Oakley, Philadelphia Section of the Mathematical Association of America; F. W. Owens, Allegheny Mountain Section of the Mathematical Association of America; F. C. Stewart, Allegheny Mountain Section of the Society for the Promotion of Engineering Education; W. H. Michener, *Secretary*, Association of Physics Teachers of Western Pennsylvania and Environs; M. H. Trytten, *Chairman*, Pennsylvania Conference of College Physics Teachers.

[1] See the report by G. W. Warner in this issue.

[2] See, for example, K. Lark-Horovitz, "Report of the committee on the teaching of physics in secondary schools," Am. J. Phys. **10**, 60 (1942).

[3] The present code permits certification in "Science" with preparation as follows: physical sciences, 9 sem. hrs. (including 3 in physics and 3 in chemistry) and biological sciences, 9 sem. hrs. (including 3 in botany and 3 in zoology).

RECENT PUBLICATIONS AND TEACHING AIDS

Pamphlets and Bulletins

Forces and atoms: the world of the physicist. K. K. Darrow. Monograph B-1306. 19 p. *Bell Telephone Laboratories* (New York), gratis. The opening lecture of a course on "Nuclear physics and theory of solids" given by the author at Smith College.

Electron microscopes and their uses. J. A. Becker and A. J. Ahern. Monograph B-1317. 16 p., 22 figs. *Bell Telephone Laboratories* (New York), gratis. An elementary account.

Fatigue of metals, some facts for the designing engineer. D. Landau. 45 p., 9 figs. *Nitralloy Corporation* (230 Park Ave., New York), gratis.

Publications of the U. S. Bureau of Home Economics. *Bureau of Home Economics* (Washington), gratis. The selection, use and care of various household appliances: *The electric vacuum cleaner*, circ. No. 834, 5 p.; *Points to look for in selecting the gas range*, circ. No. 830, 9 p.; *The electric range*, circ. No. 836, 7 p.; *The household refrigerator*, circ. No. 835, 6 p.; *Electric irons*, circ. No. 840, 7 p.

Electric equipment in the home: its care and repair. A. W. Krewatch. Bull. No. 76. 23 p. *University of Maryland* (Extension Service, College Park), gratis.

Publications of the U. S. Department of Agriculture (Department of Agriculture, Washington), gratis: *Electric light for the farmstead*, Farmers' Bull. No. 1838, 61 p.; *Simple plumbing repairs in the home*, Farmers' Bull. No. 1460, 13 p.; *Heating the farm home*, Farmers' Bull. No. 1698.

Measuring the intellectual and cultural backgrounds of teaching candidates. D. G. Ryans. 28 p., 3 figs., 13 tables. *Cooperative Test Service* (15 Amsterdam Ave., New York), gratis. An analysis of the results of the National Teacher Examinations.

Bibliography of the polarized dropping mercury electrode. 67 p. *Leeds & Northrup Co.* (4934 Stenton Ave., Philadelphia), gratis. Contains nearly 800 references, arranged chronologically, alphabetically according to authors, and according to applications.

Revere weights and data. 170 p. *Revere Copper and Brass Inc.* (230 Park Ave., New York), gratis. Contains useful conversion tables and data on standard copper and brass alloys.

Wheelco thermocouple data book and catalog. *Wheelco Instrument Co.* (Harrison and Peoria Sts., Chicago), gratis. Contains various pertinent physical tables, information on how to construct thermocouples, and recommendations for checking thermocouples and pyrometers.

Cathode-ray instruments for all purposes. 68 p., illustrated. *Allen B. DuMont Laboratories* (Passaic, N. J.), gratis. Includes notes on the specification of cathode-ray equipment.

Motion Pictures

Curves of color. 16 mm, sound, 10 min. *General Electric Co.* (Dept. 318-6, Schenectady, N. Y.), loaned gratis. Color analysis, and why it is important.

Aerodynamics. 36 p., 7 figs., *Univ. of Chicago Press*, 15 cts. A guide for use with the Erpi instructional films, *Theory of flight* and *Problems of flight*.

Trade and Government Periodicals

Cenco News Chats. *Central Scientific Co.* (Chicago), gratis.

The Laboratory. *Fisher Scientific Co.* (Pittsburgh), gratis.

Research Progress. *Westinghouse Research Laboratories* (East Pittsburgh), gratis.

Radiography and Clinical Photography. *Eastman Kodak Co.* (Rochester), limited free circulation.

The Ohmite News. *Ohmite Manufacturing Co.* (4835 Flournoy St., Chicago), gratis. Resistors.

Bakelite Review. *Bakelite Corp.* (30 East 42nd St., New York), gratis.

General Radio Experimenter. *General Radio Co.* (30 State St., Cambridge, Mass), gratis.

Tin and Its Uses. *Battell Memorial Institute* (505 King Ave., Columbus, O.), gratis.

Consumers' Guide. *Department of Agriculture* (Washington), limited free circulation. The January, 1942 issue is devoted to numerous suggestions for increasing the life and usefulness of household appliances and equipment.

Report of the Secretary of the American Association of Physics Teachers

THE executive committee of the American Association of Physics Teachers held two meetings at Princeton University on December 28, 1941. Members present were: A. G. Worthing, presiding; W. L. Cheney, P. A. Constantinides, T. D. Cope, P. E. Klopsteg, C. J. Lapp, K. Lark-Horovitz, Louise S. McDowell, W. H. Michener, R. F. Paton, W. B. Pietenpol, D. Roller, F. G. Slack, R. M. Sutton and L. W. Taylor. Other members of the Association present by invitation were H. A. Barton, L. I. Bockstahler, W. P. Davey, H. K. Hughes, R. A. Patterson, F. Palmer, H. D. Smyth and M. H. Trytten.

Reports were heard from the officers of the Association and from the chairmen of the following committees: Awards, R. M. Sutton; National defense, R. A. Patterson; Membership, R. C. Gibbs; Physics in secondary education, K. Lark-Horovitz; Tests and testing, C. J. Lapp; Letter symbols and abbreviation, H. K. Hughes; Richtmyer memorial lecture, T. D. Cope. These committees, together with the committees on terminology and on physics in relation to medical education were authorized to continue work in 1942. M. H. Trytten was added to the committee on physics in secondary education, and R. C. Colwell was named to succeed P. E. Klopsteg on the committee for the Richtmyer memorial lecture.

As the result of a suggestion made by Professor Gibbs in his report, the following motions were passed: that the executive committee express to the American Institute of Physics its concern about the post-war adjustment of physicists and signify its willingness to cooperate in any endeavor that the Institute may initiate looking toward preparation for the period after the war; and that the American Institute of Physics be asked to study the relation of the profession of physics to Labor and to formulate a policy.

L. I. Bockstahler reported for the nominating committee of 1941. H. M. Fry, H. K. Hughes and W. J. Jackson were appointed as tellers for the 1941 election; and F. L. Brown, R. L. Edwards, F. C. McDonald, W. Weniger and J. G. Winans, as members of the nominating committee for 1942. P. E. Klopsteg was nominated to succeed himself as representative of the Association on the governing board of the American Institute of Physics. C. J. Lapp, R. M. Sutton and K. Lark-Horovitz were chosen as representatives of the Association before the American Council on Education during 1942.

H. A. Barton, Director of the American Institute of Physics, discussed various activities of the Institute and also called attention to the recommendation of the executive committee of the Institute that the member societies suspend the extra 5-percent allowance which they have been making for the support of the Institute.

The present editor of the AMERICAN JOURNAL OF PHYSICS was chosen by the executive committee to succeed himself for a term of three years. Upon his recommendation T. B. Brown and A. T. Jones were appointed associate editors for the period 1942–1944. The editor was authorized to issue a cumulative index at the end of 1942 covering the first ten volumes of the journal and, if it appears desirable, to include with it an index to selected articles on the instructional and cultural aspects of physics that have appeared in American and British journals during the same ten-year period.

Attention was called to the fact that the grant made for the development of the journal by the Carnegie Foundation for the Advancement of Teaching expires in 1942. Owing to the excellent financial condition of the Association, the committee deemed it unnecessary to ask for continuation of the grant. It was agreed that financial support is needed for the program of the Cooperative Committee on Science Teaching, and K. Lark-Horovitz was authorized to represent the Association in securing it.

The secretary stated that all seven regional chapters had submitted reports on their activities in 1941. It was voted to approve the application of the Illinois State Association of Physics Teachers for recognition as a regional chapter. R. F. Paton joined the executive committee as representative of this new chapter.

It was voted that the Association accept the invitation extended to it to hold regional meetings in June, 1942 at the Pennsylvania State College and, with the Pacific Division, A.A.A.S., at the University of Utah.

The annual business meeting.—The eleventh annual business meeting convened in the Palmer Laboratory of Physics, Princeton University, at 10 A.M., December 30, 1941. President Worthing presided. Approximately 150 members were present.

The minutes of the tenth annual meeting were approved as published in the journal [Am. J. Phys. **9**, 132 (1941)]. The actions taken by the executive committee at its meetings on December 28 were reviewed by the secretary and, after some discussion, were approved without dissent. Similar action was taken with regard to the report of the treasurer [Am. J. Phys. **10**, 56 (1942)].

H M. Fry reported for the tellers that 336 ballots—representing 37.3 percent of the membership—had been received in the election of officers for 1942, that 331 of these ballots could be identified as coming from members in good standing, and that the results of the election were as follows:

President: A. A. KNOWLTON
Vice President: L. W. TAYLOR
Members of the Executive Committee (two years): LOUISE S. MCDOWELL, K. LARK-HOROVITZ.

M. W. White read by request a communication from President-Elect Knowlton, who was unable to be present because of serious illness in his family. The secretary was directed to send telegrams conveying the greetings of the Association to Professor Knowlton and to members participating in the regional meeting at Dallas, Texas. By motion carried without dissent, the secretary was instructed to convey to H. D. Smyth and the staff of the Palmer Laboratory the thanks of the Association for the many courtesies that had been extended to it.

THOMAS D. COPE, *Secretary*

Attendance at the Princeton Meeting

THE registration of those in attendance lists 146 members of the Association and 54 nonmembers. Members who registered were:

Gladys A. Anslow, Smith College; R. H. Bacon, Frankford Arsenal; C. A. Bareuther, Drexel Institute of Technology; E. F. Barker, University of Michigan; H. A. Barton, American Institute of Physics; V. P. Barton, Goucher College; P. F. Bartunek, Rensselaer Polytechnic Institute; C. E. Bennett, University of Maine; W. H. Bessey, North Carolina State College; R. A. Beth, Michigan State College; E. M. Bigsbee, Junior College of Connecticut; H. Louisa Billings, Smith College; O. H. Blackwood, University of Pittsburgh; L. I. Bockstahler, Northwestern University; W. I. Book, University of Pennsylvania; R. B. Bowersox, University of Toledo; J. C. Boyce, Massachusetts Institute of Technology; G. P. Brewington, Lawrence Institute of Technology; C. L. Brightman, Syracuse University; Brother Bruno, Cathedral High School (Indianapolis); T. B. Brown, George Washington University; J. W. Buchta, University of Minnesota; W. L. Cheney, George Washington University; F. F. Cleveland, Illinois Institute of Technology; J. J. Coop, Washington College; P. A. Constantinides, Wright Junior College of Chicago; T. D. Cope, University of Pennsylvania; F. P. Cowan, Rensselaer Polytechnic Institute; S. W. Cram, Kansas State Teachers College; H. Crew, Northwestern University; C. W. Curtis, Western Reserve University; W. P. Cunningham, Tower Hill School; W. P. Davey, Pennsylvania State College; Elsie Dollman, Hunter College; D. C. Duncan, Pennsylvania State College; J. R. Dunning, Columbia University; V. E. Eaton, Wesleyan University; R. L. Edwards, Miami University; J. D. Elder, Lynchburg College; C. R. Fountain, Amherst College; M. Katherine Frehafer, Goucher College; H. M. Fry, Franklin and Marshall College; M. W. Garrett, Swarthmore College; Helen T. Gilroy, Beaver College; A. N. Guthrie, Rhode Island State College; M. C. Harrington, Drew University; H. H. Hartzler, Goshen College; S. K. Haynes, Brown University; A. Hazeltine, Stevens Institute of Technology; S. M. Heflin, Virginia Military Institute; J. J. Heilemann, Ursinus College; D. M. Hill, Philadelphia College of Pharmacy and Science; W. L. Hole, Michigan State Normal College; G. W. Horton, Wabash College; F. F. Householder, University of Akron; R. H. Howe, Denison University; H. L. Howes, University of New Hampshire; H. K. Hughes, University of Newark; G. F. Hull, Dartmouth College; E. Hutchisson, University of Pittsburgh; M. C. Hylan, Raritan Arsenal; Brother Godfrey John, La Salle College; A. T. Jones, Smith College; J. M. Kelley, Loyola High School (Baltimore); E. C. Kemble, Harvard University; P. M. Kendig, Franklin and Marshall College; E. H. Kennard, Cornell University; A. L. King, Rensselaer Polytechnic Institute; D. E. Kirkpatrick, Queens College; P. E. Klopsteg, Central Scientific Company; B. Kurrelmeyer, Brooklyn College; J. Kurshan, Cornell University; C. J. Lapp, University of Iowa; K. Lark-Horovitz, Purdue University; H. Levene, Central High School (Philadelphia); D. P. LeGalley, Philadelphia College of Pharmacy and Science; F. W. Loomis, Massachusetts Institute of Technology; J. J. McCarthy, St. John's University; Louise S. McDowell, Wellesley College; W. C. McQuarrie, Lafayette College; K. V. Manning, Pennsylvania State College; Sister Anastasia Maria, Immaculata College; Sister Grace Marie, College of Chestnut Hill; D. C. Martin, Southeastern Louisiana College; Helen A. Messenger, Hunter College; W. H. Michener, Carnegie Institute of Technology; Nora M. Mohler, Smith College; J. C. Morris, Office of Scientific Personnel; L. B. Morse, College of the City of New York; S. W. Nile, Princeton University; H. N. Otis, Hunter College; F. Palmer, Haverford College; R. F. Paton, University of Illinois; R. A. Patterson, Rensselaer Polytechnic Institute; G. B. Pegram, Columbia University; H. A. Perkins, Trinity College; W. B. Pietenpol, University of Colorado; M. L. Pool, Ohio State University; J. S. Rinehart, Wayne University; E. M. Rogers, St. Paul's School; V. Rojansky, Union College; D. Roller, Hunter College; Y. K. Roots, Western College; G. Rosengarten, Philadelphia College of Pharmacy and Science; H. K. Schilling, Pennsylvania State College; R. S. Shankland, Case School of Applied Science; R. S. Shaw, College of the City of New York; S. Sonkin, College of the City of New York; F. G. Slack, Vanderbilt University; A. W. Smith, Ohio State University; H. L. Smith, Michigan State Normal College; L. E. Smith, Denison University; H. D. Smyth, Princeton University; G. W. Stewart, University of Iowa; W. W. Stifler, Columbia University; Hildegard Stucklen, Mt. Holyoke College; Rosalyn Sussman, University of Illinois; R. M. Sutton, University of Minnesota; H. N. Swenson, Queens College; L. W. Taylor, Oberlin College; E. W. Thatcher, Union College; J. A. Tiedman, United States Naval Academy; J. A. Tobin, Boston College; M. H. Trytten, University of Pittsburgh; F. G. Tucker, Oberlin College; C. W. Ufford, Allegheny College; G. D. Van Dyke, Earlham College; A. T. Waterman, Yale University; B. B. Watson, University of Pennsylvania; W. Webb, Pennsylvania State College; A. H. Weber, Saint Louis University; Dorothy W. Weeks, Wilson College; M. R. Wehr, Drexel Institute of Technology; N. E. Wheeler, Colby College; M. W. White, Pennsylvania State College; W. C. Wineland, Morehead State Teachers College; E. E. Witmer, University of Pennsylvania; P. I. Wold, Union College; K. S. Woodcock, Bates College; J. W. Woodrow, Iowa State College; A. G. Worthing, University of Pittsburgh; W. R. Wright, Swarthmore College; P. R. Yoder, Juniata College; A. Zeleny, University of Minnesota; J. Zeleny, Yale University; M. W. Zemansky, College of the City of New York.

School Physics and the National Emergency

IT is suggested that many readers of the AMERICAN JOURNAL OF PHYSICS may be in a position to exert their influence in meeting the problem presented in a letter which the American Institute of Physics recently sent to all State Superintendents of Education and which was essentially as follows:

> The present emergency demands that every effort be made to increase the supply of personnel trained in the applications of the physical sciences. They will be called upon to put physics to work in the defense industries, in the civil service of the Government and in the armed forces. Our country has been caught desperately short in the supply of such men because careers in physics have not been brought adequately to the attention of high school students. Tens of thousands of such individuals are necessary now and many more will be called in the immediate future.
>
> To reach all high school pupils, we ask your cooperation in bringing these facts to the attention of your superintendents of schools, supervisors and principals.
>
> All boys and girls showing a natural aptitude for laboratory work and a reasonable skill in mathematics and physics should be given the opportunity to acquire as much physics instruction as possible. They will be of maximum usefulness if they have had at least two years of mathematics.
>
> In particular, the need is great for people who are trained in the fundamentals of electricity. We ask you, therefore, to instruct all vocational guidance officers to urge these youngsters to go on to college wherever this is financially possible, majoring in physics, mathematics and engineering fundamentals. All radio amateurs especially should be urged to continue their education immediately after graduation, either by entering college or by taking appropriate courses at the nearest engineering defense training center.
>
> Information and advice as to the need for scholarships and financial support for particularly able students should be brought at once to the attention of the nearest engineering defense training center.

In a final paragraph attention was called to a list of the principal ESMDT centers which was enclosed with the letter and to the fact that the Institute will attempt to keep State Departments of Education informed of any new developments in the application of physics in the war effort.

DIGEST OF PERIODICAL LITERATURE

CHECK LIST OF PERIODICAL LITERATURE

Direct processes for making photographic prints in colors. C. E. K. Mees, *J. Frank. Inst.* **233**, 41–50 (1942). An account of two recently developed processes for making prints in natural colors from a color transparency.

On the modern development of celestial mechanics. C. L. Siegel, *Am. Math. Mo.* **48**, 430–435 (1941). A brief account of the more important of the modern results connected with the names of Bruns, Poincaré and Sundman.

The scientific work of Vito Volterra. E. S. Allen, *Am. Math. Mo.* **48**, 516–519 (1941).

Walther Nernst, a great physicist, passes. R. A. Millikan, *Sci. Mo.* **54**, 85–86 (1942).

The work and personality of Walther Nernst. A. Einstein, *Sci. Mo.* **54**, 195–196 (1942).

Your voice and the telephone. F. L. Hunt, *Sci. Mo.* **54**, 138–148 (1942). Some of the great advances which have been made in telephone apparatus and methods.

Men of science and higher education in a democracy. O. Blüh, *Sci. Ed.* **25**, 299–307 (1941). For a companion article on the applications of the author's generalizations to physics teaching, see *Am. J. Phys.* **10**, 39 (1942).

Rare gases in everyday use. F. P. Gross, Jr., *J. Chem. Ed.* **18**, 533–539 (1941).

The solution of a.c. circuit problems. L. A. Pipes. *J. App. Phys.* **12**, 685–691 (1941). This new method for determining the various currents in a general n-mesh circuit greatly reduces the computational labor since only real quantities are involved and the procedure is one of matrix multiplication, which is easily performed by means of a calculating machine.

Physics in 1941. T. H. Osgood, *J. App. Phys.* **13**, 3–21 (1942). A survey.

How bats "see" in the dark. E. Teale, *Pop. Sci. Mo.* **138**, 102–104 (1941). Extensive experiments carried on at Harvard University show conclusively that a bat flies by sound rather than by sight. It emits sounds of frequencies 30,000 to 70,000 vib/sec at the rate of 30 cries per second. As the bat approaches an obstacle, the number of cries increases to 50 per second.

The functions of physics courses in the engineering curricula. E. P. Slack, *J. Eng. Ed.* **32**, 361–364 (1941).

Minimum acceptable achievement in mechanics. G. N. Cox, *J. Eng. Ed.* **32**, 341–345 (1941). The material to be covered and the degree of mastery which should be expected of engineering students in applied mechanics.

Teaching dynamics. S. Timoshenko, *J. Eng. Ed.* **32**, 463–466 (1941). On the teaching of mechanics to engineering students.

Science sequence and enrolments in the secondary schools of the United States. G. W. Hunter, L. Spore, *Sci. Ed.* **25**, 359–379 (1941).

Locally constructed apparatus for use in high school physics. R. I. Misner, *Sci. Ed.* **25**, 391–396 (1941). Includes many specific references to books and articles that contain directions for making simple apparatus.

Some more mechanic's own tools. S. Munday, *J. Sci. Inst.* **18**, 223–224 (1941).

Properties vs. performance of present-day antifreeze solutions. D. H. Green, H. Lamprey, E. E. Sommer, *J. Chem. Ed.* **18**, 488–492 (1941). A discussion of methanol, ethanol and ethylene glycol as antifreeze and coolant materials. Laboratory and field tests indicate that glycol, properly inhibited against corrosion and foaming, is the best general antifreeze material.

Synthetic resins and plastics. H. A. Neville, *J. Chem. Ed.* **19**, 9–14 (1942). A review article.

Monomolecular film demonstrations. A. L. Kuehner, *J. Chem. Ed.* **19**, 27–28 (1942). Two methods of forming a monomolecular film and of measuring its area are described. In the first, the entire surface of distilled water in a paraffin-lined tray is covered with the film. In the second, the film is formed within a ring of nylon thread floating on the surface of water. Palmitic acid, cetyl alcohol, stearic acid, oleic acid and mycricyl alcohol form satisfactory films. Values of molecular dimensions calculated from these rapidly performed experiments compare favorably with Langmuir's more accurate results.

The measurement of surface tension. T. H. Hazelhurst, *J. Chem. Ed.* **19**, 61–65 (1942). Describes the apparatus, theory and typical results for a student experiment on the determination of coefficients of surface tension by the convenient and accurate method of maximum bubble pressure [Sugden, *J. Chem. Soc.* **121**, 858 (1922); **125**, 27 (1924)].

Some unsolved problems of theoretical dynamics. G. D. Birkhoff, *Science* **94**, 598–600 (1941).

An Important Announcement Concerning the Summer Retraining of Secondary School Teachers

IT is beginning to appear that the training of the needed masses of skilled operators and maintenance men for defense work in the factories and in the field will require a disproportionate amount of time unless these individuals possess some background of scientific knowledge, particularly physics and mathematics. Since the staffs of colleges and universities are already heavily loaded with defense courses and research, the next logical step is to enlist secondary school science teachers as teachers of basic material in additional defense courses. Because many of these teachers are poorly prepared, the ESMDT has found it possible to approve in principle that, where courses are needed and the supply of teachers is inadequate, the teachers themselves may be trained in the leading colleges and universities as a legitimate part of ESMDT activities. Every physics staff should fully explore its ability to cooperate in such training. If the entire staff is already teaching full strength, courses for teachers might be offered that utilize the facilities of large laboratories but are taught by physicists brought in from smaller institutions.